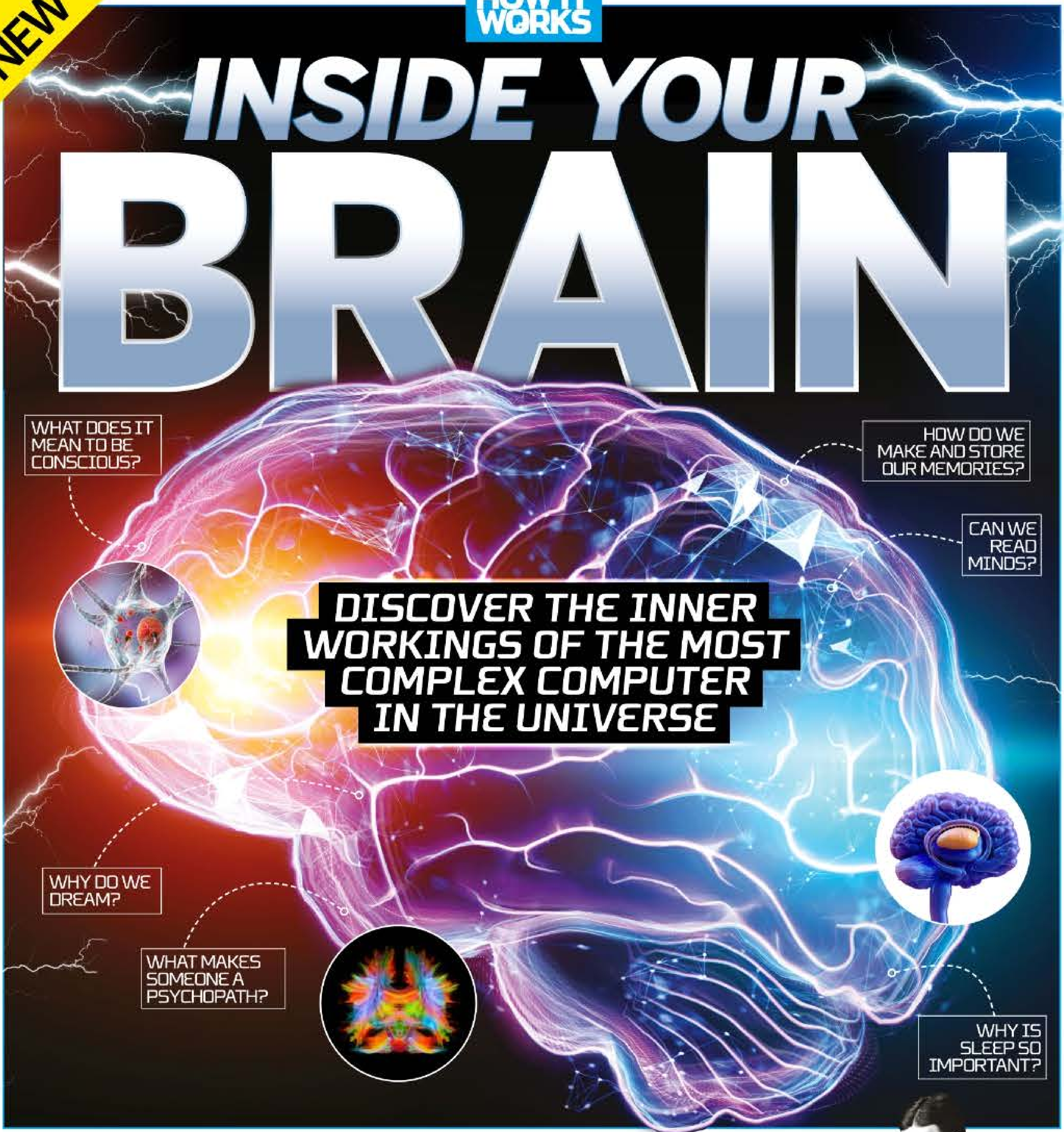
NEW

HOW IT WORKS

INSIDE YOUR BRAIN



WHAT DOES IT MEAN TO BE CONSCIOUS?

HOW DO WE MAKE AND STORE OUR MEMORIES?

CAN WE READ MINDS?

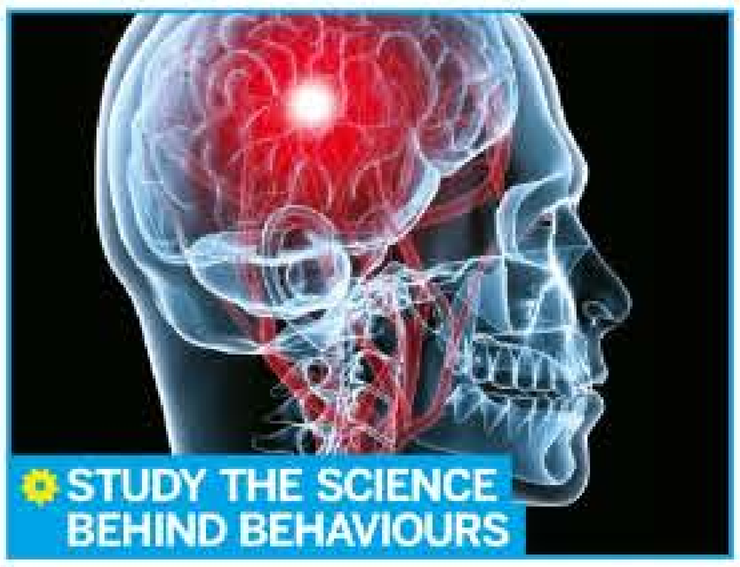
DISCOVER THE INNER WORKINGS OF THE MOST COMPLEX COMPUTER IN THE UNIVERSE

WHY DO WE DREAM?

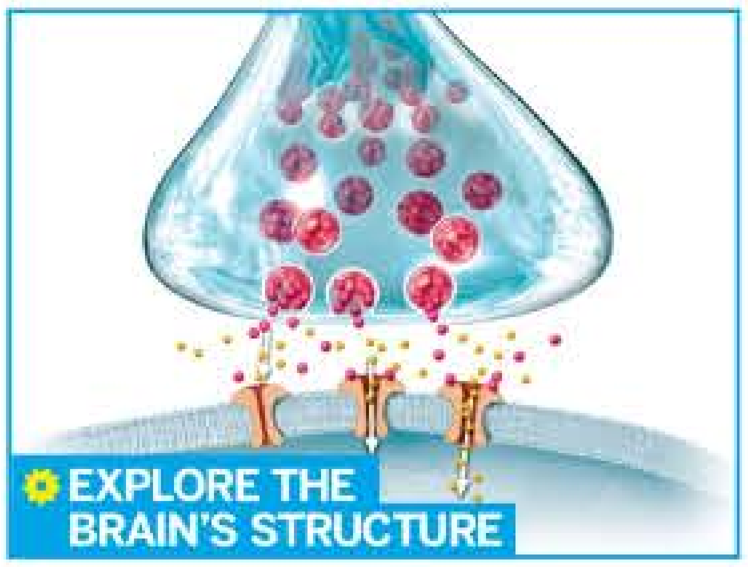
WHAT MAKES SOMEONE A PSYCHOPATH?

WHY IS SLEEP SO IMPORTANT?

Digital Edition



STUDY THE SCIENCE BEHIND BEHAVIOURS



EXPLORE THE BRAIN'S STRUCTURE

MEET THE FATHER OF NEUROSCIENCE

FUTURE

FIRST EDITION

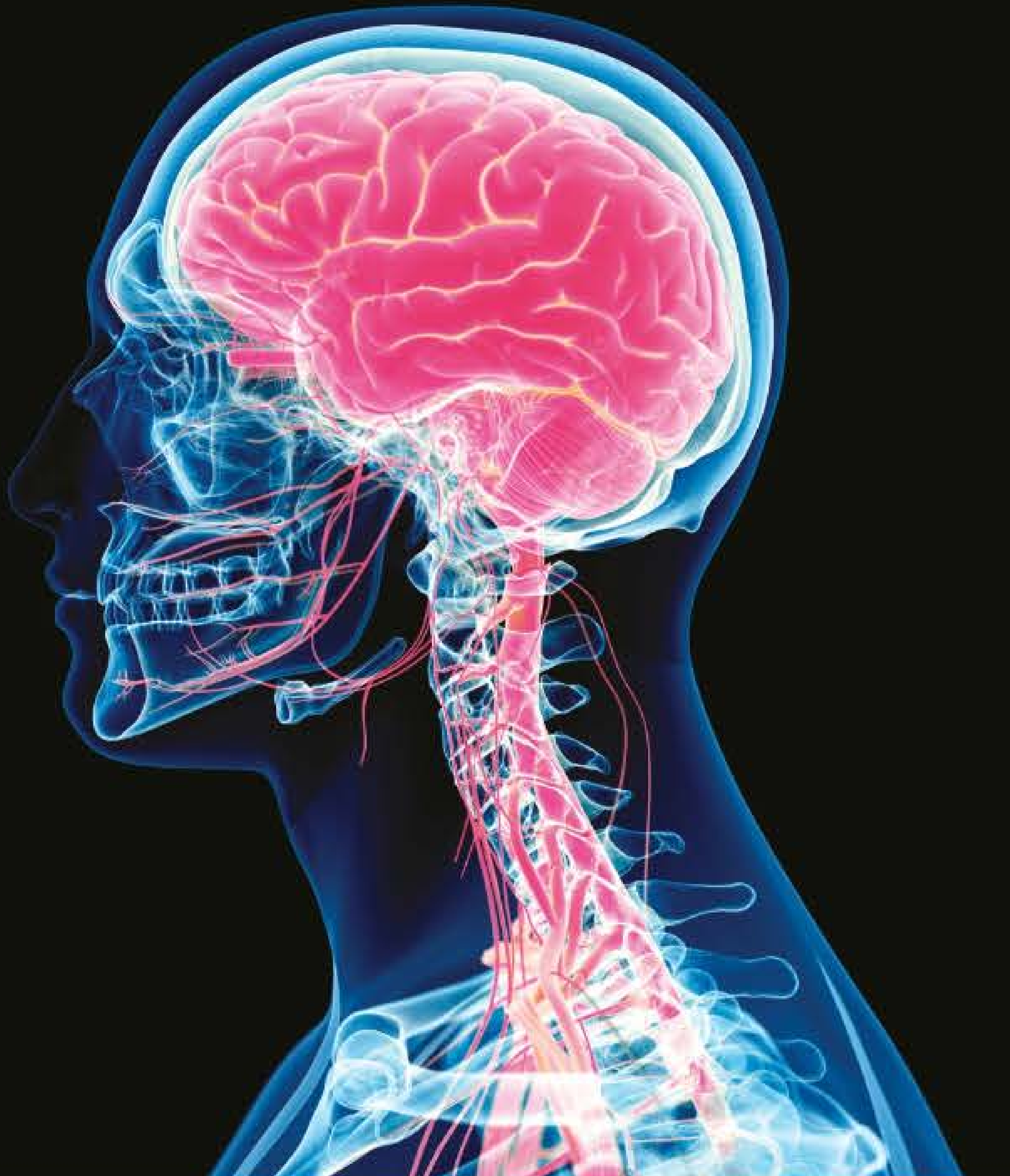
■ IMAGINATION ■ EMOTIONS ■ MINDTRICKS ■ EXPERIMENTS

Welcome to

HOW IT WORKS

INSIDE YOUR BRAIN

It's no secret that the human brain is a marvellous thing. From the movements you rely on every day to the emotions you express, the dreams that feel real and the thoughts that whizz through your mind, the brain controls it all. Centuries of study have yielded many answers to its countless mysteries. We know about the synapses and neurons that make up the brain, and leading surgeons can now map someone's brain and perform once impossible operations. But there is still so much that we don't understand. What does it really mean to be conscious? Why do we have cognitive biases when the facts contradict us? And why are some people psychopaths who see the world in a totally different way? In this book you'll explore some of the answers to these questions, chart the life of a pioneering neurosurgeon and relive some of the most bizarre experiments ever conducted in the endless quest to understand the brain.



FUTURE

INSIDE YOUR BRAIN

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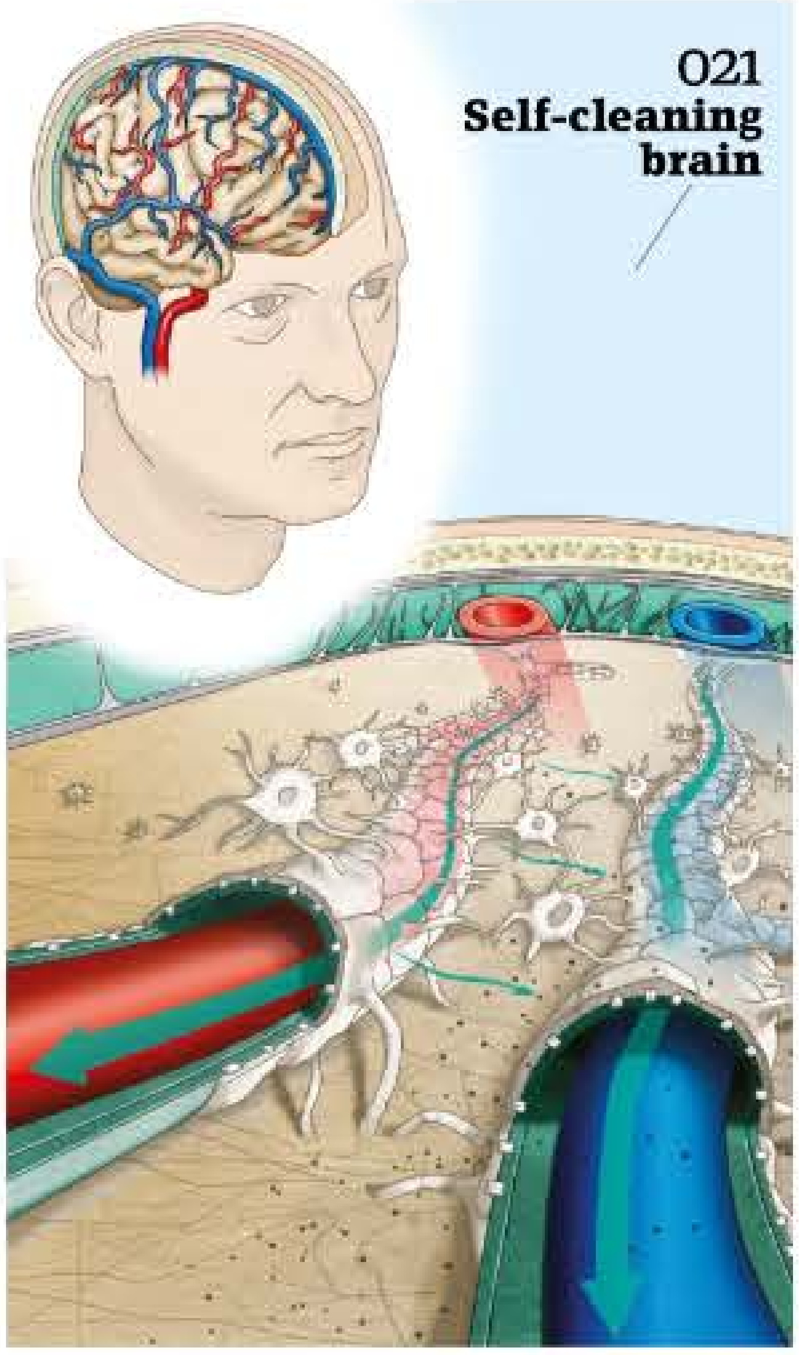

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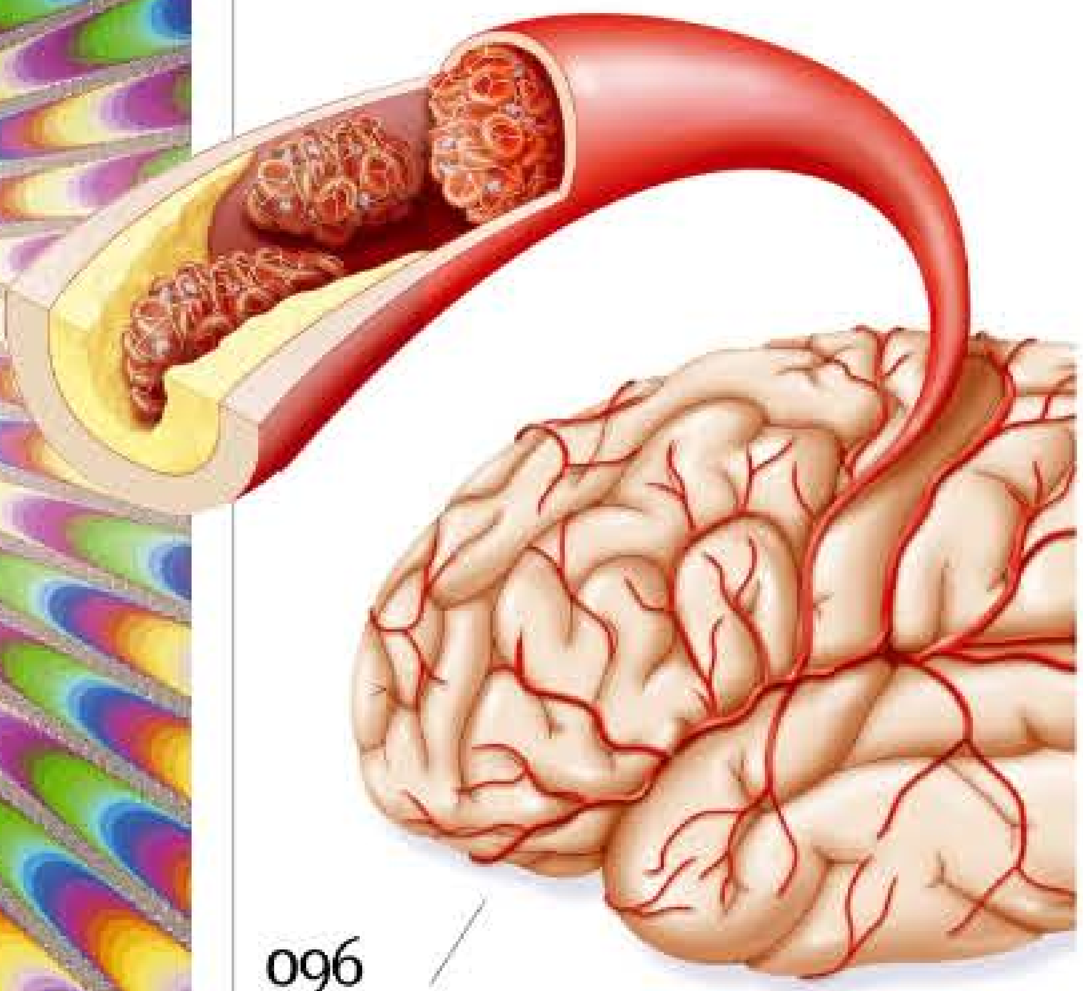

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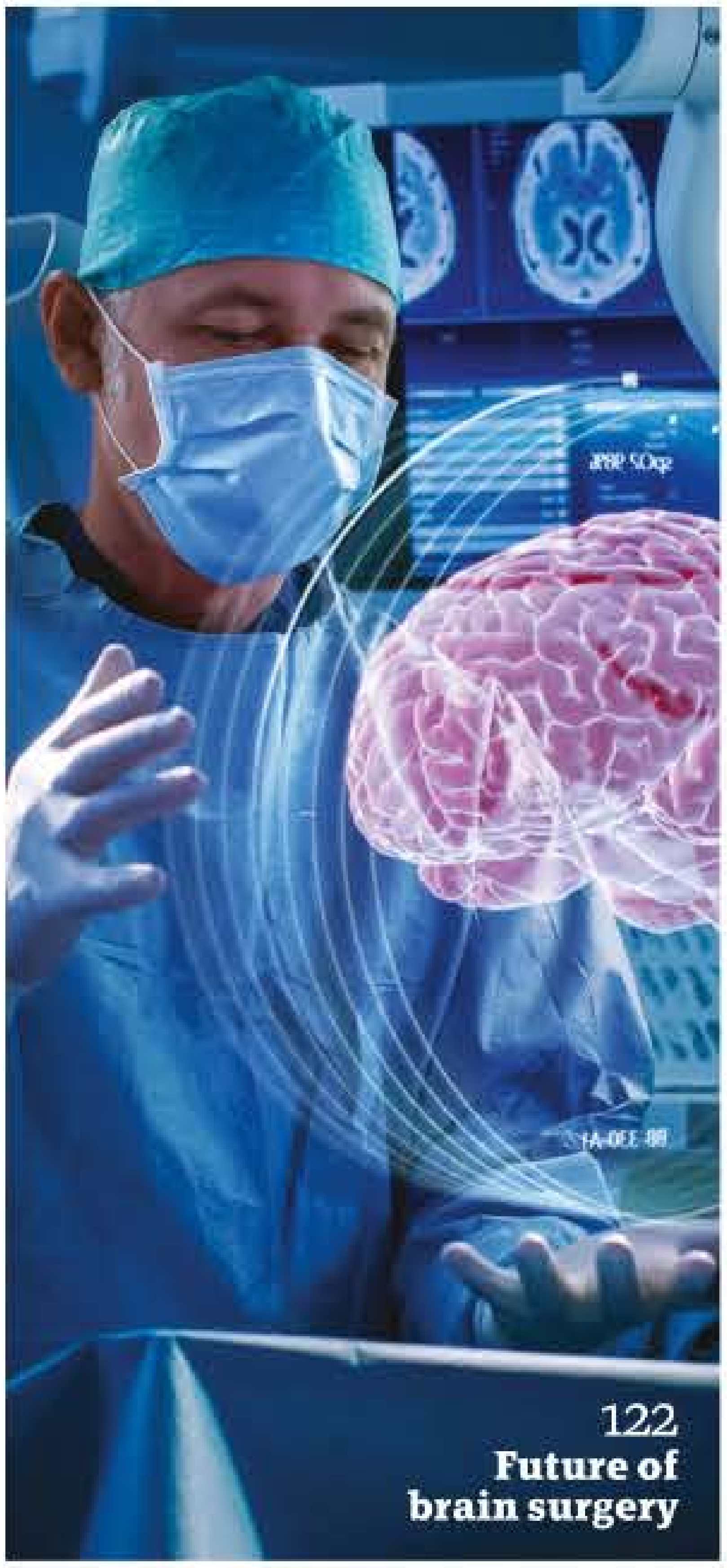

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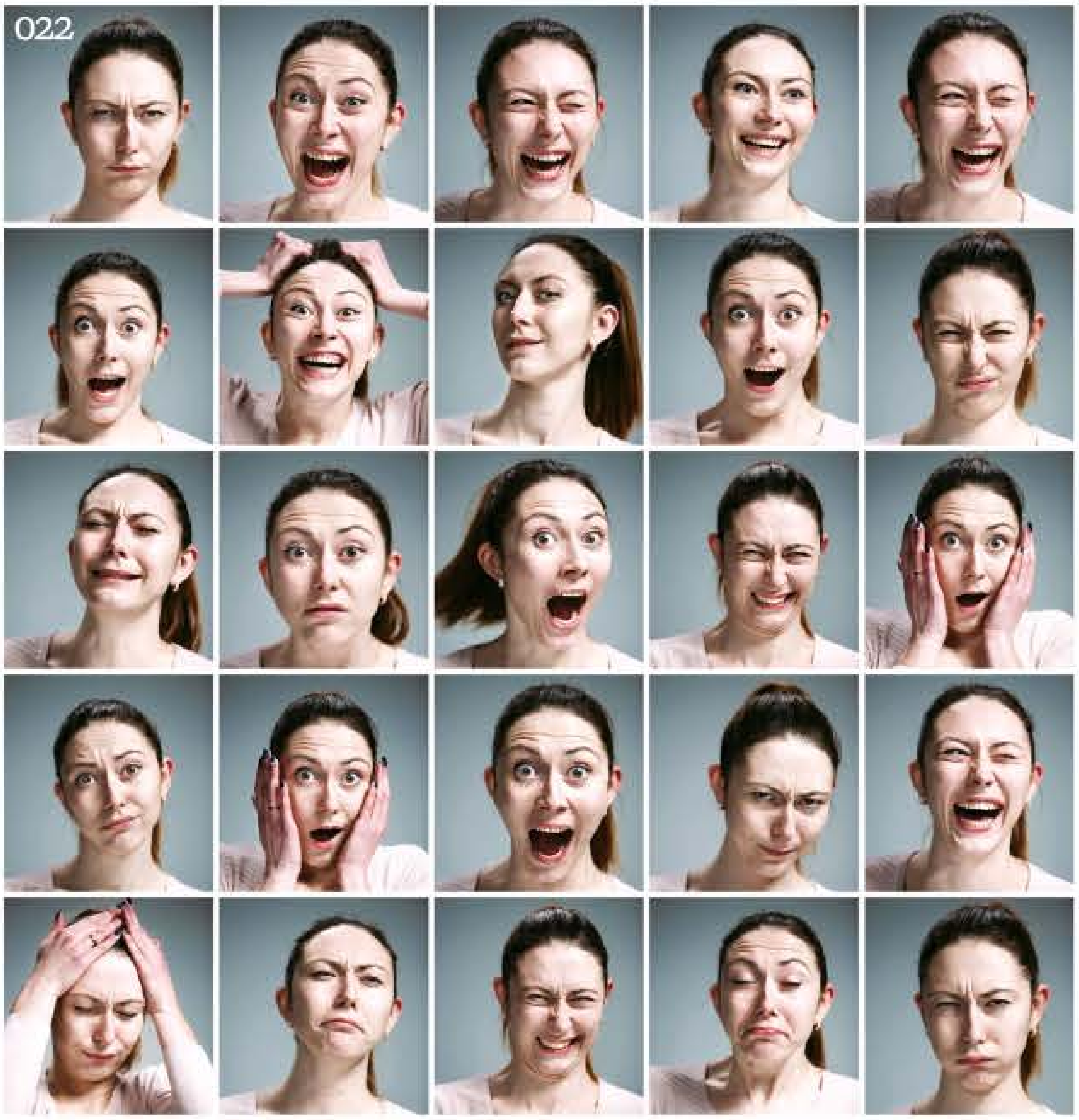
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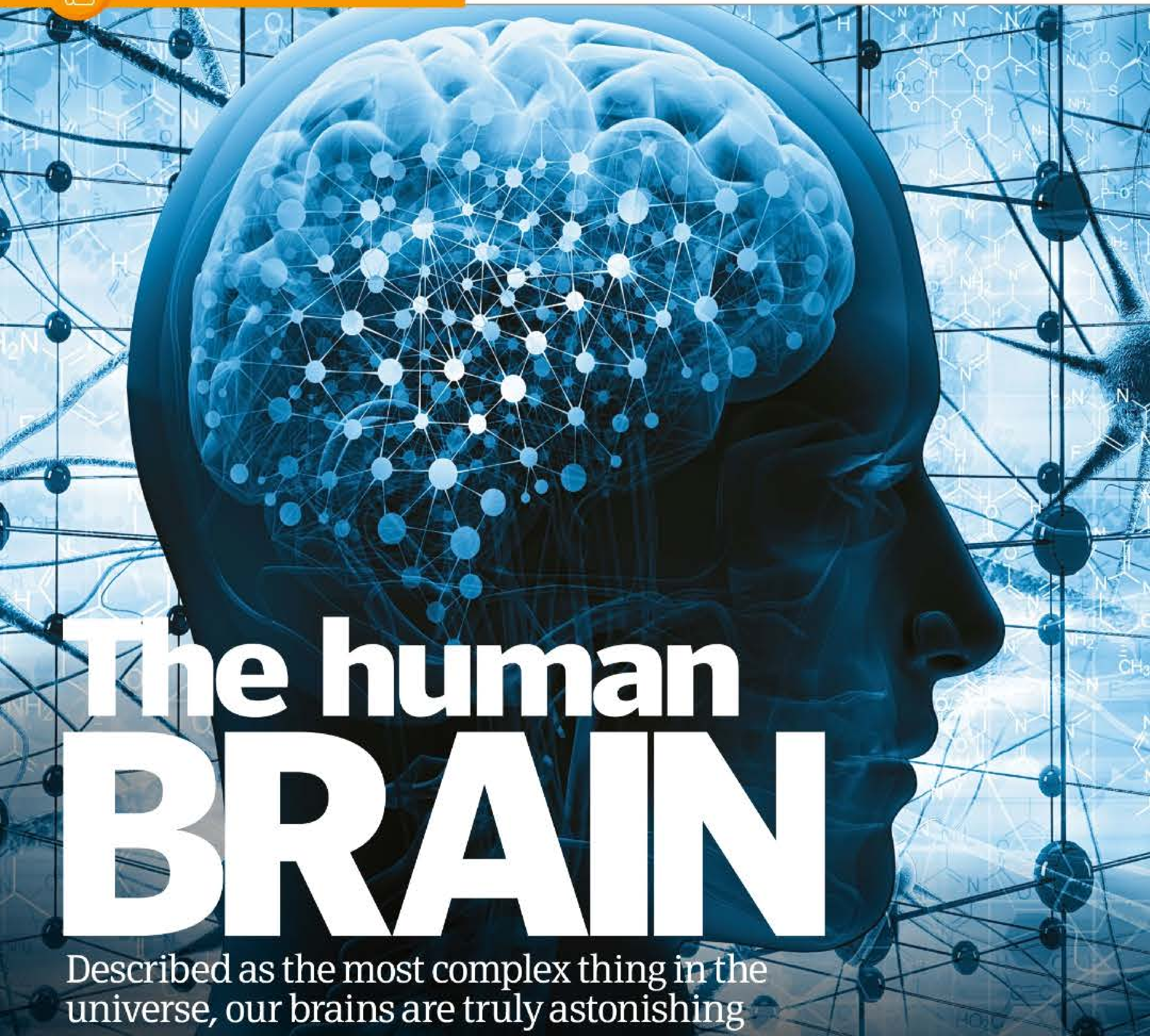


The human BRAIN

Described as the most complex thing in the universe, our brains are truly astonishing

The brain makes up just two per cent of our total body weight, but crammed inside are approximately 86 billion neurons, surrounded by 180,000 kilometres of insulated fibres connected at 100 trillion synapses. It's a vast biological supercomputer.

The cells in the brain communicate using electrical signals. When a message is sent, thousands of microscopic channels open, allowing positively charged ions to flood across the membrane. Afterwards, more than 1 million miniature pumps in each cell move the ions back again ready for the next impulse.

The cell bodies of the neurons, and their connections, are contained within the grey matter, which consumes 94 per cent of the oxygen delivered to the brain. Different areas are responsible for different functions, and wiring them together is a fatty network of fibres called white matter.

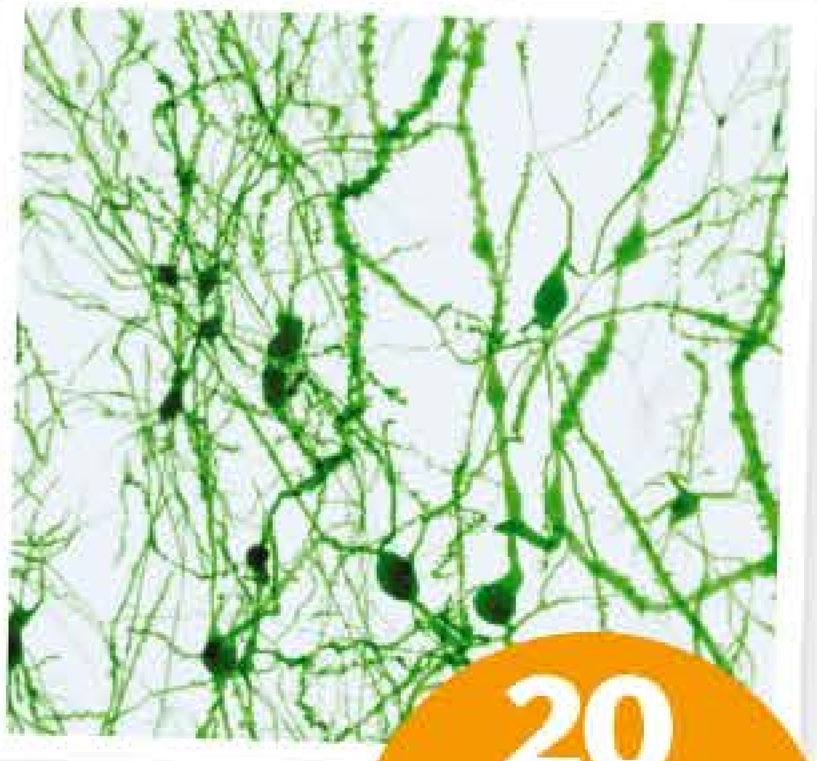
When a signal reaches the end of a nerve cell, tiny packets of chemical signals spill out onto the surrounding neurons. These connections, called synapses, allow messages to be passed from one cell to the next. Each neuron can receive thousands of inputs, coordinating them in time and space, and by type of chemical, to decide what to do next.

Scientists have been electrically and chemically stimulating the brain to see how it responds to different signals, recording electrical activity to map thoughts and using imaging like functional MRI to track the blood flow increases that reveal when nerve cells are firing. The cells of the brain can also be studied inside the lab. Thanks to these investigations we know more about this incredible structure than ever before, but our understanding is only just beginning. There is so much more to learn.

Brain development

From a single cell to an incredibly intricate network in just nine months

Within weeks of fertilisation, neural progenitors start to form; these stem cells will go on to become all of the cells of the central nervous system. They organise into a neural tube when the embryo is barely the size of a pen tip, and then patterning begins, laying out the structural organisation of the brain and spinal cord. At its peak growth rate, the developing brain can generate 250,000 new neurons every minute. By the time a baby is born, the process still isn't complete. But, by the age of two, the brain is 80 per cent of its adult size.



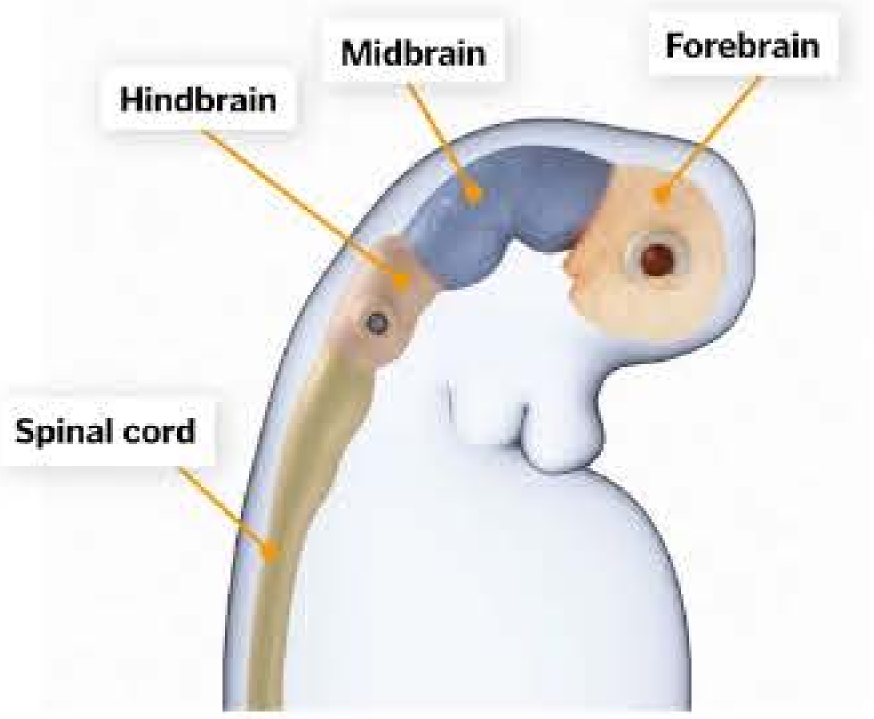
Pyramidal neurons, like these, are found in the hippocampus, cortex and amygdala

20 watts

Your brain is incredibly efficient, using less energy than a standard light bulb.

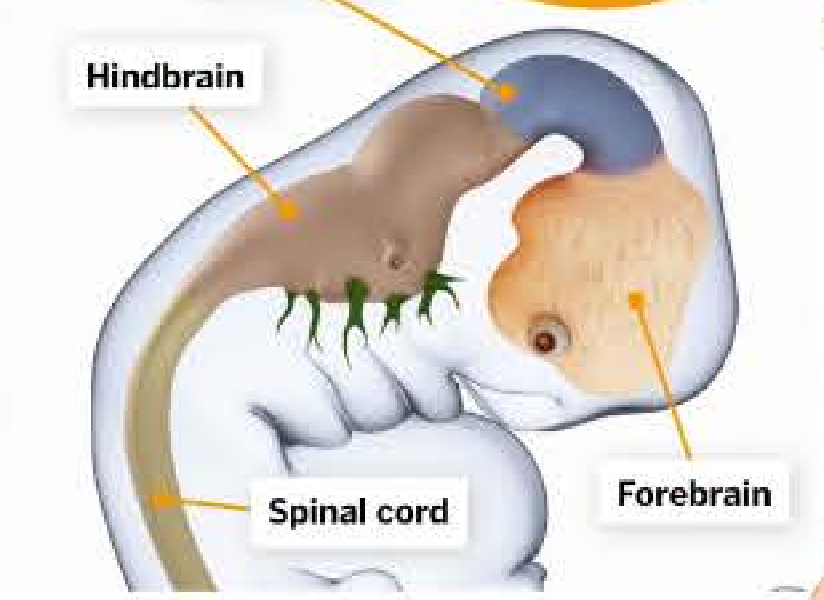
Brain formation

This astonishing structure is formed and refined as pregnancy progresses



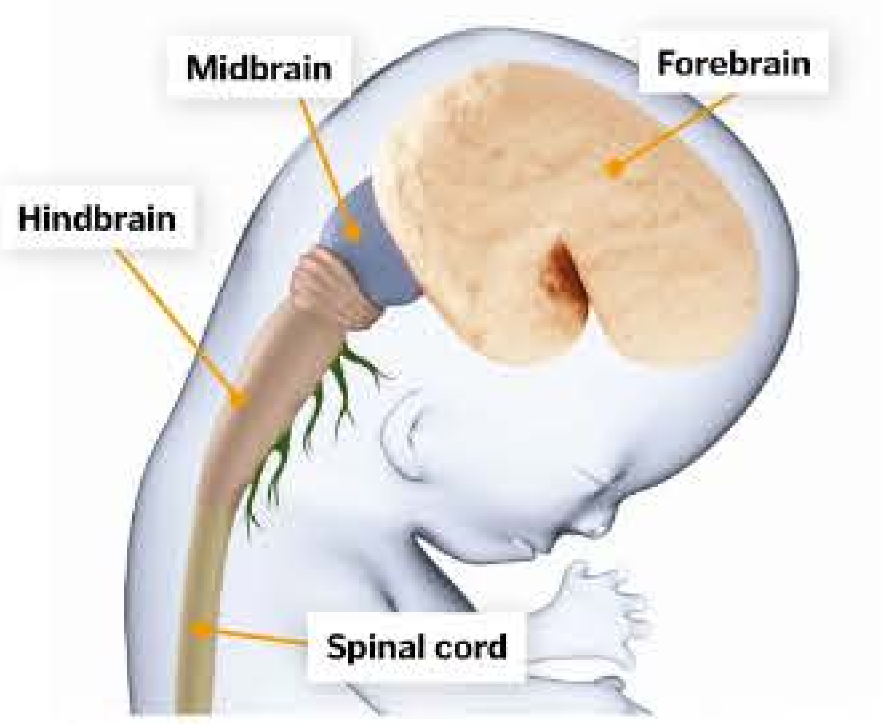
4 weeks

Brain development starts just three weeks after fertilisation. The first structure is the neural tube, which divides into regions that later become the forebrain, midbrain, hindbrain and spinal cord.



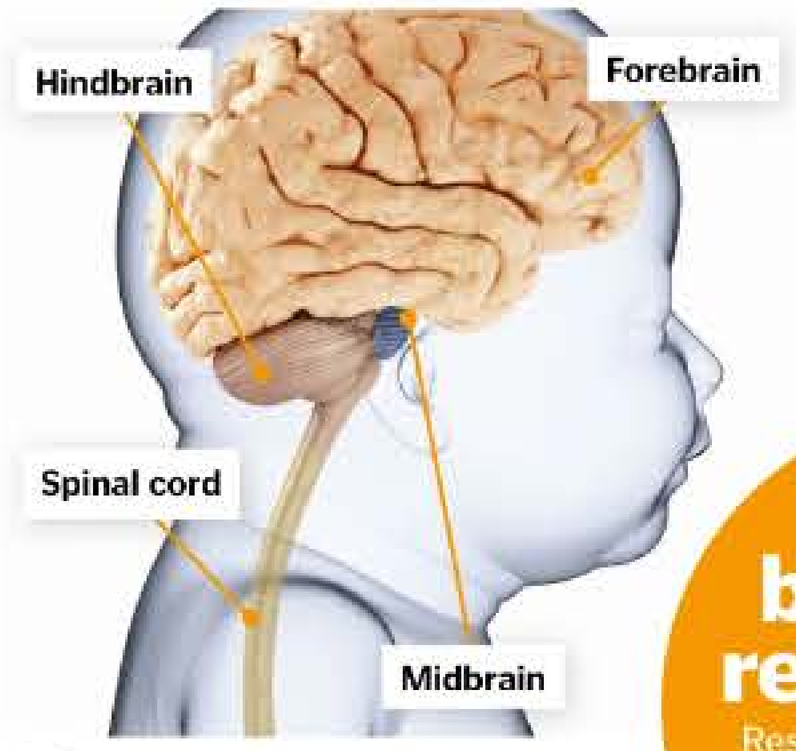
6 weeks

The pattern of the brain and spinal cord is now laid out and is gradually refined, controlled by gradients of signalling molecules that assign different areas for different functions.



11 weeks

As the embryo becomes larger, the brain continues to increase in size and neurons migrate and organise. The surface of the brain gradually begins to fold. At this point, a foetus only measures about five centimetres in length.



Birth

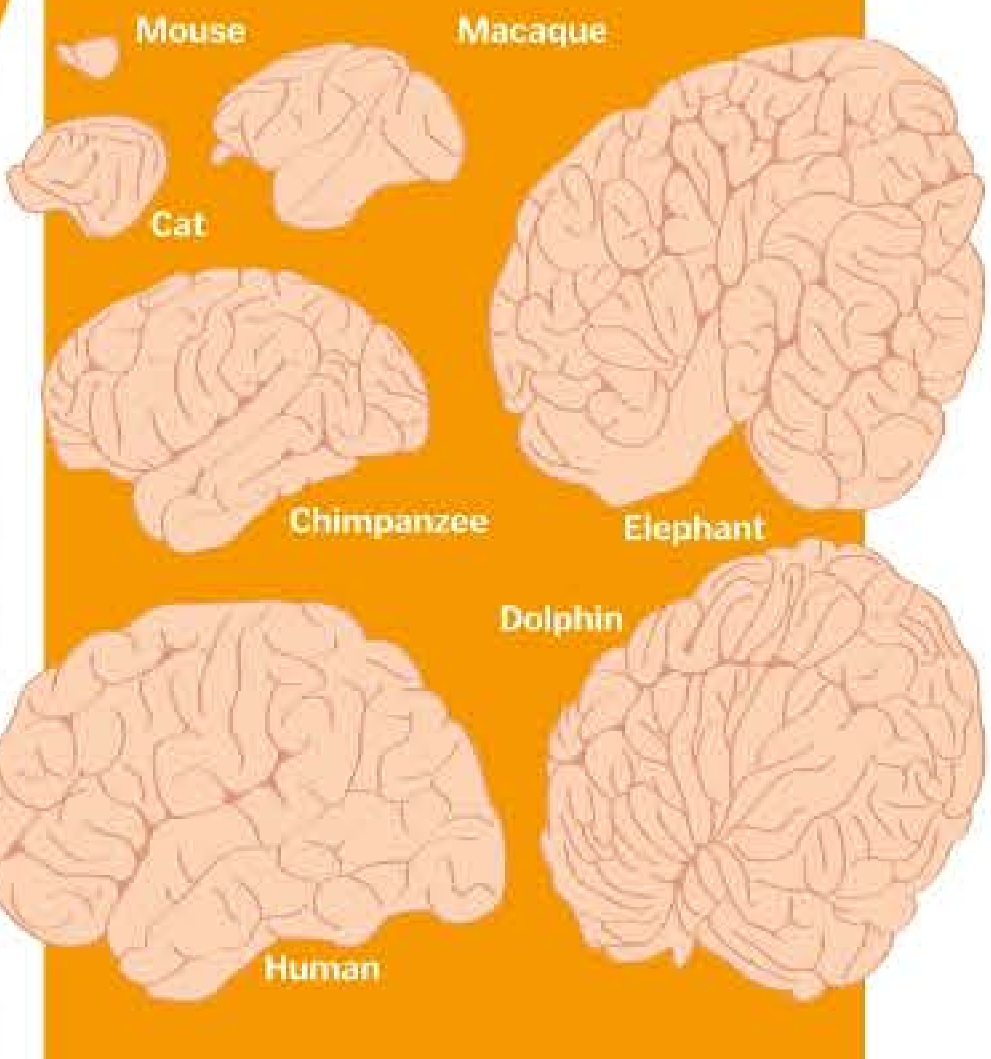
Before a baby is born, around half of the nerve cells in the brain are lost and connections are pruned, leaving only the most useful. This process continues after birth.

Why the brain is wrinkled

The brain folds in on itself to cram in more processing power

The folds and pockets of our brains are a biological rarity that we only share with a few other species, including dolphins, some primates and elephants. It's a clever evolutionary adaptation that allows intelligent species to squash a huge amount of cortical tissue into a small space, allowing enormous brainpower to be crammed into our relatively small skulls.

Folding starts during the second trimester of pregnancy, creating ridges (gyri) and fissures (sulci), but the biology behind the distinctive wrinkles is stranger than you might think. The organisation of the brain is determined by complex cascades of chemical signals, but the overall shape seems to be the result of simple physics. Grey matter sits on the outside of the brain, and during development its growth rapidly outpaces the growth of white matter underneath. This puts mechanical stress on the structure, forcing the outside to buckle and curl.



More wrinkled brains are associated with higher intelligence (brain sizes not to scale)

The brain can regenerate

Research has shown that certain areas of the adult brain can continue to produce new neurons, a process known as neurogenesis.

> "Our brains contain 86 billion neurons and 180,000 kilometres of fibres"

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Inside your brain

Delve into the make up of the human brain and discover what its major parts do

It's a computer, a thinking machine, a fatty pink organ, and a vast collection of neurons – but how does it actually work? The human brain is amazingly complex – in fact, more complex than anything in the known universe. The brain effortlessly consumes power, stores memories, processes thoughts and reacts to danger.

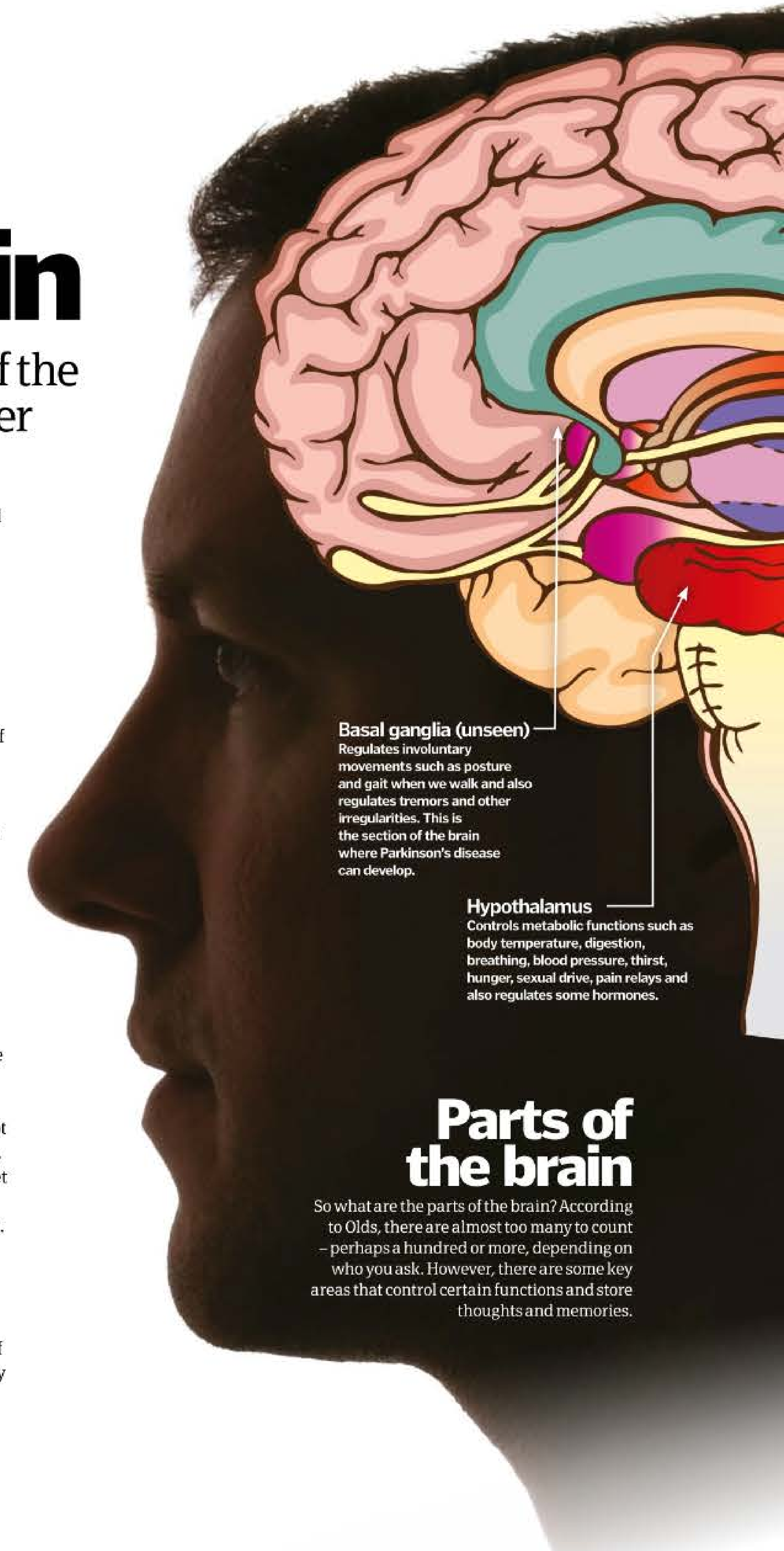
In some ways, the human brain is like a car engine. The fuel – which could be the sandwich you had for lunch or a sugar doughnut for breakfast – causes neurons to fire in a logical sequence and to bond with other neurons. This combination of neurons occurs incredibly fast, but the chain reaction might help you compose a symphony or recall entire passages of a book, help you pedal a bike or write an email to a friend.

Scientists are just beginning to understand how these brain neurons work – they have not figured out how they trigger a reaction when you touch a hot stove, for example, or why you can re-generate brain cells when you work out at the gym.

The connections inside a brain are very similar to the internet – the connections are constantly exchanging information. Yet, even the internet is rather simplistic when compared to neurons.

There are around 10,000 types of neurons inside the brain, and each one makes thousands of connections. This is how the brain processes information or determines how to move an arm and grip a surface. These calculations, perceptions, memories and reactions occur almost instantaneously, and not just a few times per minute but millions. According to Jim Olds, Research Director with George Mason University, if the internet were as complex as our solar system, then the brain would be as complex as our galaxy. In other words, we have a lot to learn. Science has not given up trying and has made recent discoveries about how we adapt, learn new information and can actually increase brain capability.

In the most basic sense, our brain is the centre of all input and outputs in the human body. Dr Paula Tallal, a Codirector of Neuroscience at Rutgers University, says the brain is constantly processing sensory information – even from infancy. "It's easiest to think of the brain in terms of inputs and outputs," says Tallal. "Inputs are sensory information, outputs are how



Basal ganglia (unseen)
Regulates involuntary movements such as posture and gait when we walk and also regulates tremors and other irregularities. This is the section of the brain where Parkinson's disease can develop.

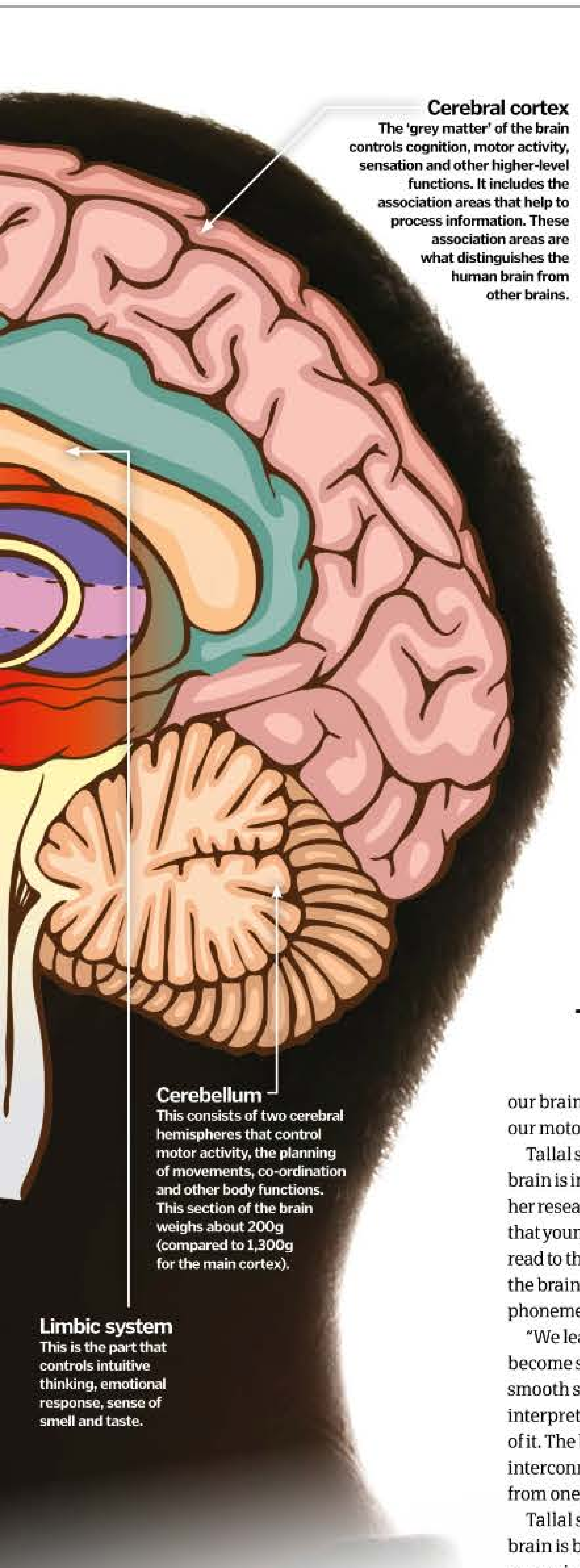
Hypothalamus
Controls metabolic functions such as body temperature, digestion, breathing, blood pressure, thirst, hunger, sexual drive, pain relays and also regulates some hormones.

Parts of the brain

So what are the parts of the brain? According to Olds, there are almost too many to count – perhaps a hundred or more, depending on who you ask. However, there are some key areas that control certain functions and store thoughts and memories.

Functions of the cerebral cortex

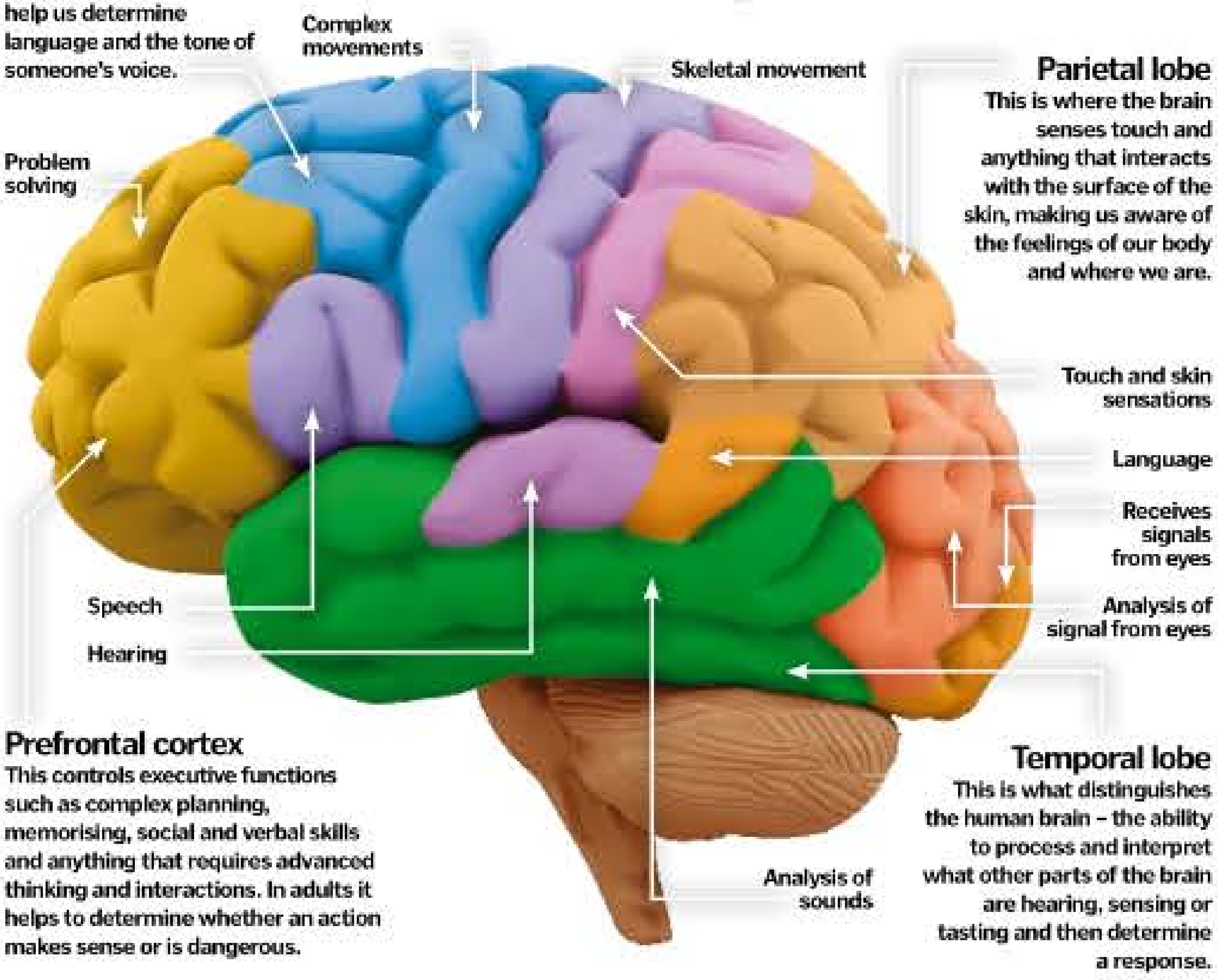
The cerebral cortex is the wrinkling part that shows up when you see pictures of the brain



Cerebral cortex
The 'grey matter' of the brain controls cognition, motor activity, sensation and other higher-level functions. It includes the association areas that help to process information. These association areas are what distinguishes the human brain from other brains.

Cerebellum
This consists of two cerebral hemispheres that control motor activity, the planning of movements, co-ordination and other body functions. This section of the brain weighs about 200g (compared to 1,300g for the main cortex).

Limbic system
This is the part that controls intuitive thinking, emotional response, sense of smell and taste.



Frontal lobe
This primarily controls senses such as taste, hearing and smell. Association areas might help us determine language and the tone of someone's voice.

Parietal lobe
This is where the brain senses touch and anything that interacts with the surface of the skin, making us aware of the feelings of our body and where we are.

Prefrontal cortex
This controls executive functions such as complex planning, memorising, social and verbal skills and anything that requires advanced thinking and interactions. In adults it helps to determine whether an action makes sense or is dangerous.

Temporal lobe
This is what distinguishes the human brain – the ability to process and interpret what other parts of the brain are hearing, sensing or tasting and then determine a response.

> *"In a sense, the main function of the brain is in ordering information – interpreting the outside world and making sense of it"*

our brain organises that information and controls our motor systems."

Tallal says one of the primary functions of the brain is in learning to predict what comes next. In her research for *Scientific Learning*, she has found that young children enjoy having the same book read to them again and again because that is how the brain registers acoustic cues that form into phonemes (sounds) to become spoken words.

"We learn to put things together so that they become smooth sequences," she says. These smooth sequences are observable in the brain, interpreting the outside world and making sense of it. The brain is actually a series of interconnected 'superhighways' that move 'data' from one part of the body to another.

Tallal says another way to think about the brain is by lower and upper areas. The spinal cord moves information up to the brain stem, then up into the cerebral cortex, which controls thoughts and memories. Interestingly, the brain really does work like a powerful computer in determining not only movements but registering memories that can be quickly recalled.

According to Dr Robert Melillo, a neurologist and the founder of the Brain Balance Centers (www.brainbalancecenters.com), the brain actually predetermines actions and calculates the results about a half-second before performing them (or even faster in some cases). This means that when you reach out to open a door, your brain has already predetermined how to move your elbow and clasp your hand – it may even have simulated this movement more than once, before you even perform the action.

Another interesting aspect to the brain is that there are some voluntary movements and some involuntary. Some sections of the brain might control a voluntary movement such as patting your knee to a beat. Another section controls involuntary movements, such as the gait of your walk, which is passed down from your parents.

Left or right brained?

Actually, you're neither. Discover the truth behind the way we think

It's true that the different sides of the brain perform different tasks, but do these anatomical asymmetries really define our personalities? Some psychologists argue that creative, artistic individuals have a more developed right hemisphere, while analytical, logical people rely more heavily on the left side of the brain, but so far the evidence for this two-sided split has been lacking.

A team at the University of Utah attempted to answer the question by dividing the brain up into 7,000 regions and analysing the fMRI scans of over 1,000 people in order to determine whether the networks on one side of the brain were stronger than the networks on the other.

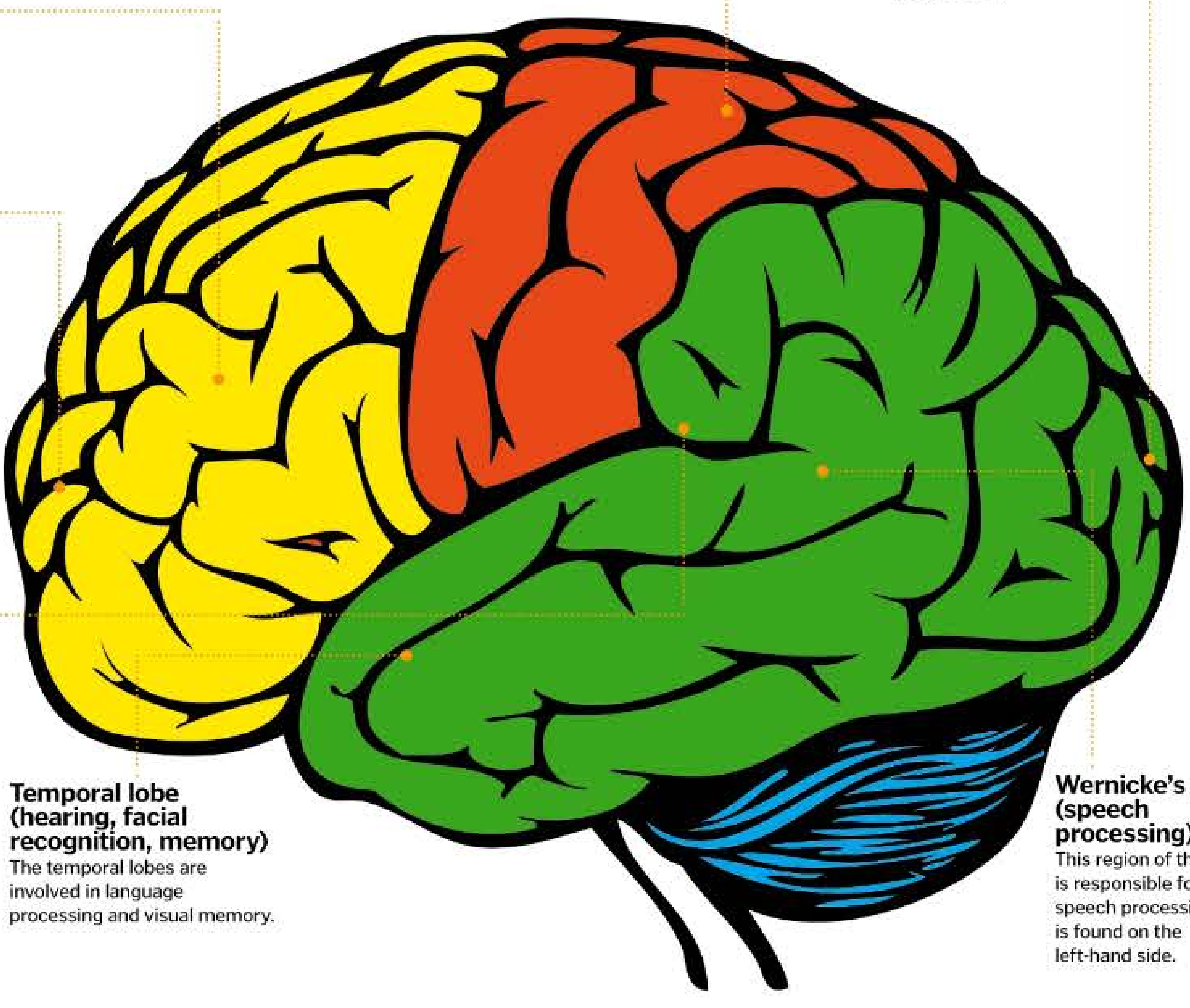
Despite the popularity of the left versus right brain myth, the team (who published their findings in the journal *PLOS ONE*) found no difference in the strength of the networks in each hemisphere or in the amount we use either side of our brains. Instead, they showed that the brain is more like a network of computers. Local nerves can communicate more efficiently than distant ones, so instead of sending every signal across from one hemisphere to the other, neurones that need to be in constant communication tend to develop into organised local hubs.

Hubs with related functions cluster together, preferentially developing on the same side of the brain and thereby allowing the nerves to communicate rapidly on a local scale. One example is language processing – in most people, the regions of the brain involved in speech, communication and verbal reasoning are all located on the left-hand side.

Some areas of the brain are less symmetrical than others, but both hemispheres are used relatively equally, albeit for different things. There is nothing to say you can't be a brilliant scientist and a great artist too – just look at Leonardo da Vinci.

Examining the human brain

What do the different parts of the brain actually do?



Parietal lobe (pressure, taste)
The parietal lobes handle sensory information and are involved in spatial awareness and navigation.

Occipital lobe (vision)
Incoming information from the eyes is processed at the back of the brain in the visual cortex.

Broca's area (speech)
Broca's area is responsible for the ability to speak and is almost always found on the left side of the brain.

Frontal lobe (planning, problem solving)
At the front of each hemisphere is a frontal lobe. The left side is more heavily involved in speech and verbal reasoning, while the right side handles attention.

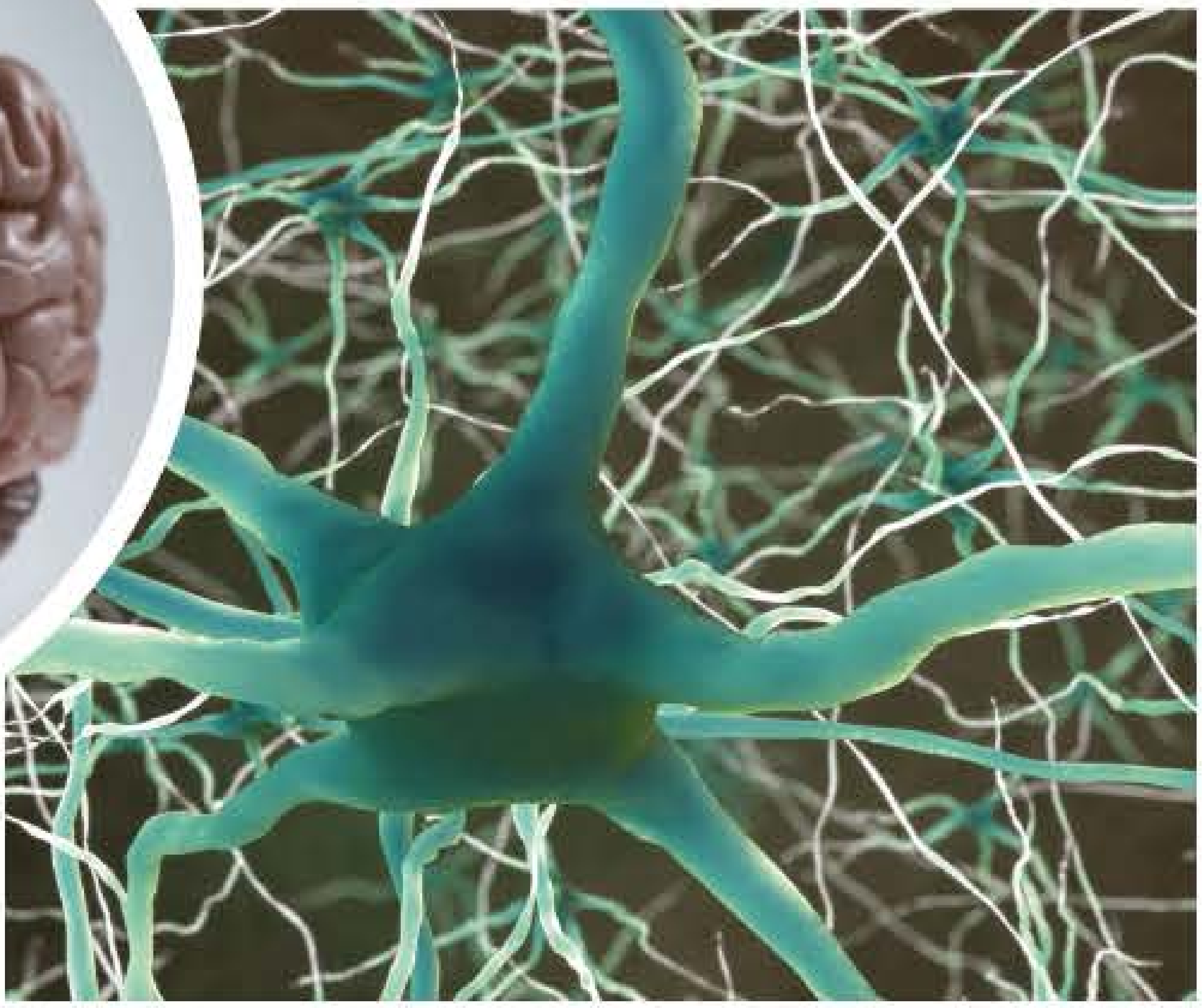
Auditory cortex (hearing)
The auditory cortex is responsible for processing information from the ears and can be found on both sides of the brain in the temporal lobes.

Temporal lobe (hearing, facial recognition, memory)
The temporal lobes are involved in language processing and visual memory.

Wernicke's area (speech processing)
This region of the brain is responsible for speech processing and is found on the left-hand side.

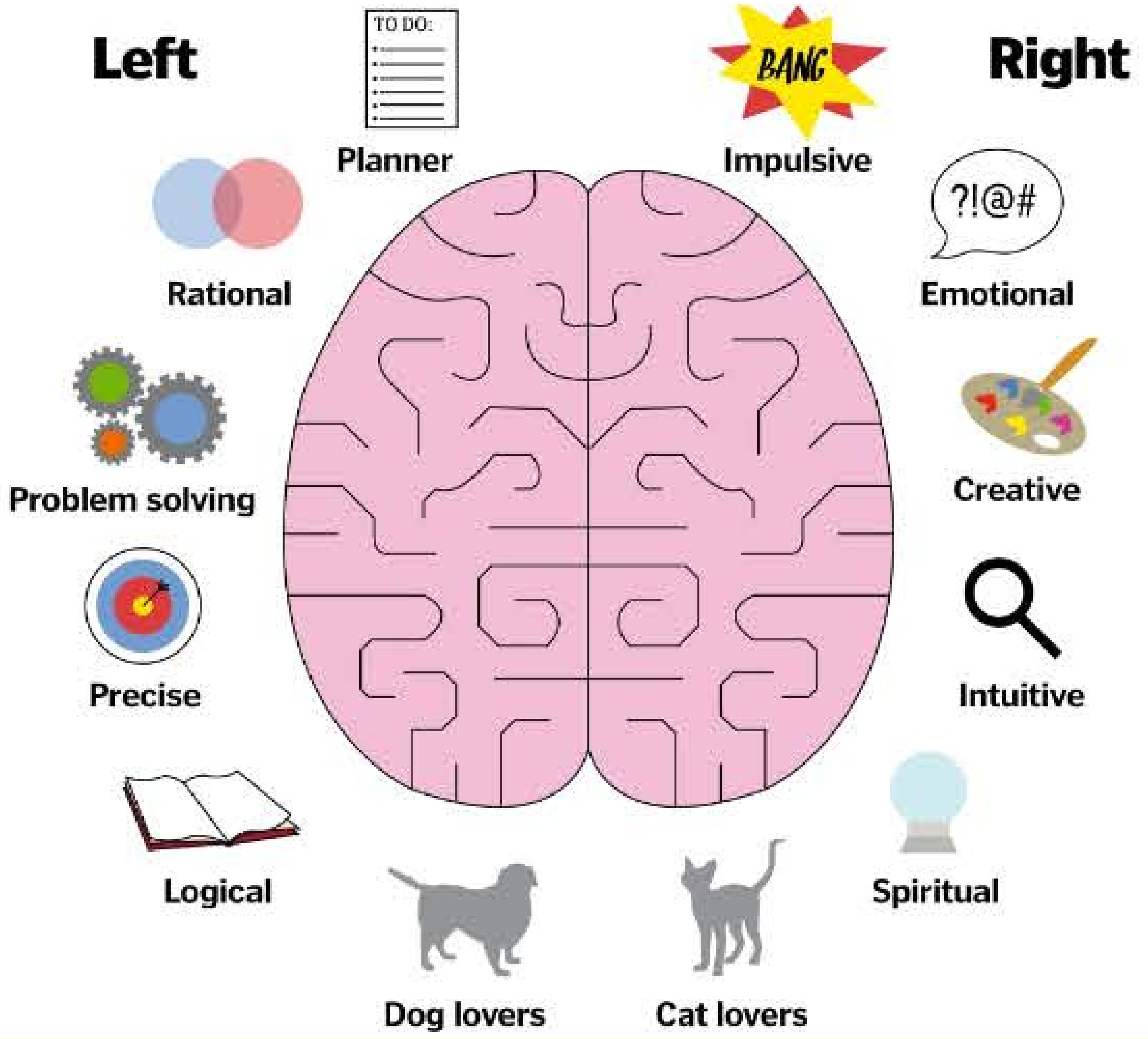
The human brain is so powerful that it took 82,944 computer processors 40 minutes to simulate just one second of its activity

A microscopic image of the brain's extremely complex neural network



Myth-taken identity

The left versus right brain myth is actually based on Nobel Prize-winning science. In the 1940s, a radical treatment for epilepsy was trialled; doctors severed the corpus callosum of a small number of patients, effectively splitting their brains in two. If a patient was shown an object in their right field of view, they had no difficulty naming it, but if they were shown the same object from the left, they couldn't describe it. Speech and language are processed on the left side of the brain, but the information from the left eye is processed on the right. The patients were unable to say what they saw, but they could draw it. Psychologists wondered whether the differences between the two hemispheres could create two distinctive personality types: left-brained and right-brained.



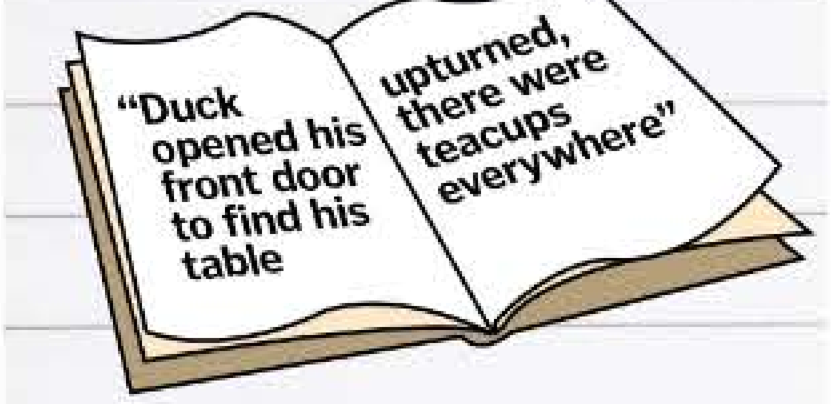
Give your brain a fun workout

1 Boost your memory

Look at this list of items for one minute, then cover the page and see how many you can remember:

Coin	Telephone	Grape
Duck	Potato	Pillowcase
Key	Teacup	Bicycle
Pencil	Match	Table

Difficult? Try again, but this time make up a story in your head, linking the objects together in a narrative.


"Duck opened his front door to find his table
upturned, there were teacups everywhere"

...You get the idea. Make it as silly as you like; strange things are much more memorable than the mundane.

2 Slow brain ageing

Learning a new language is one of the best ways to keep your brain active. Here are four new ways to say hello:

- Polish: Cześć! (che-sh-ch)
- Russian: Zdravstvuj (zdrah-stvooy)
- Arabic: Marhaba (mar-ha-ba)
- Swahili: Hujambo (hud-yambo)

© Corbis: Thinkstock

Brain cells

Find out what's really going on inside your head

Your brain is an incredible thing. It is one of the most complex structures in the known universe, and for decades, scientists have been teasing it apart to find out what it's made of and how it works.

The brain is an electrical and chemical circuit, and nerve cells, or neurons, are the components. They each have a cell body, which contains their genetic code, an axon to transmit electrical impulses and dendrites to receive them.

They are connected together at junctions known as synapses. When an impulse arrives, packets of molecules are released, passing the message on. Each neuron makes thousands of connections, producing the complicated patterns that drive human thought.

There are hundreds of different types of neuron in the brain, categorised according to their unique structure and function, and more are being discovered all the time. But they can't function on their own. They are supported by a network of glial cells – a name that literally means 'glue'.

There are three main types of glial cell. Oligodendrocytes have fatty branches, which they wrap around the conducting axons of nerve cells like the plastic coating on electrical wires. This provides insulation, preventing signals from getting crossed and speeding up their transmission along the chain.

Microglia are part of the immune system and act like an in-house cleanup crew, tracking down pathogens and clearing debris from the brain. Then there's the star-shaped astrocytes, which reach between nerve cells and blood vessels with their long, thin arms, shuttling nutrients, mopping up waste products and even getting involved with chemical signalling.

How many cells?

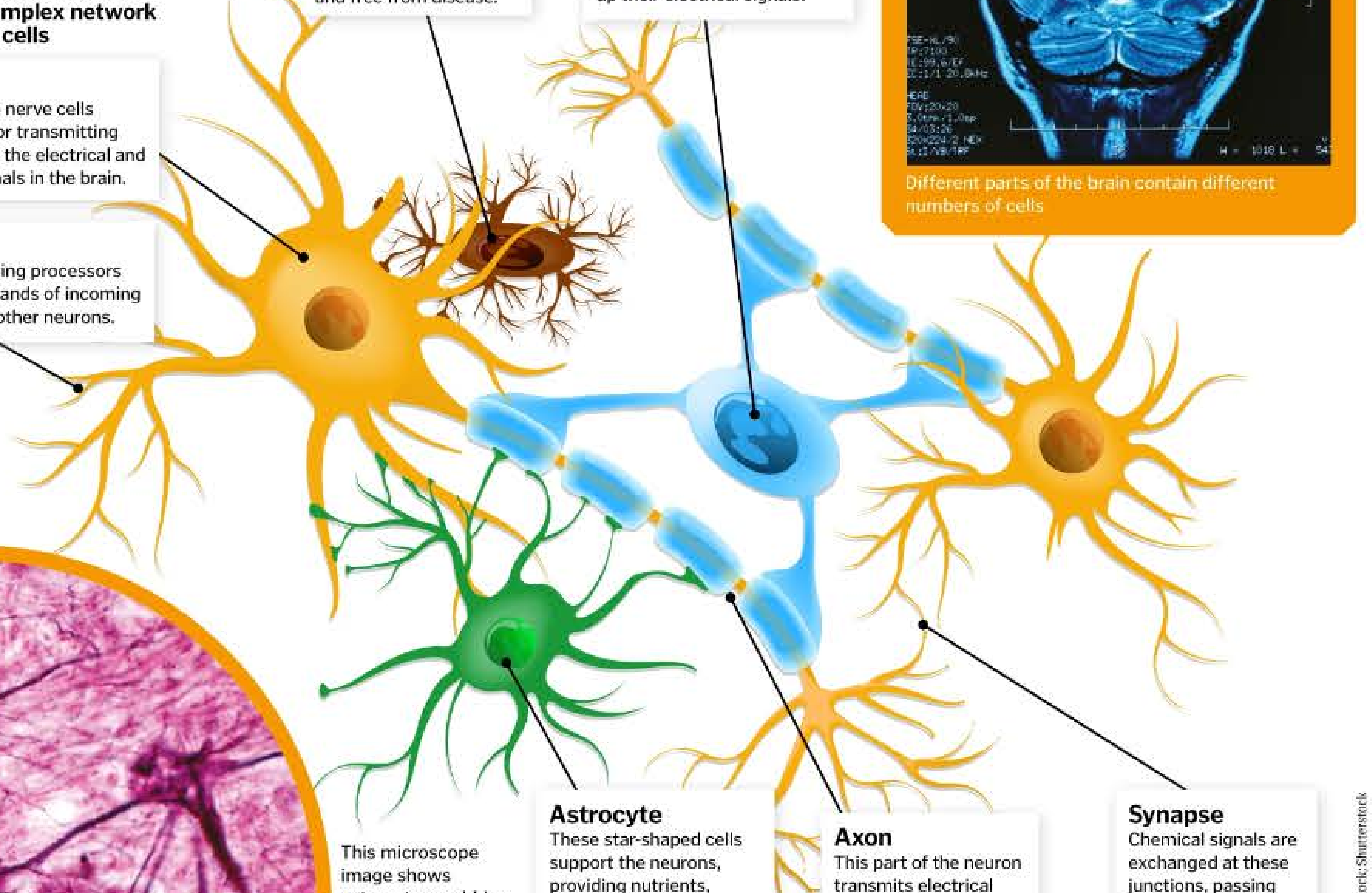
It's hard to know exactly how many cells are in the brain. Individual neurons have long, thin axons and branching trees of dendrites that cross over with their neighbours, forming a tangled mass that is almost impossible to accurately examine. One of the most commonly quoted estimates is 100 billion neurons, with anywhere between three and ten times as many supporting glial cells, but the latest research suggests that these numbers are in fact wrong.

Using a new technique for counting cells, scientists have come up with a different number. Each cell has one nucleus, and they can be stained up to make it easy to tell whether they belong to a neuron or a glial cell. Rather than count them under a microscope, the researchers popped the cells open and turned them into a 'soup' so that they could be quickly counted by machine. Using this technique, they revealed that there are closer to 86 billion neurons and about the same number of glial cells – far fewer than expected.

Different parts of the brain contain different numbers of cells

Under the microscope

A closer look at the brain reveals a complex network of different cells



Neuron
These are the nerve cells responsible for transmitting and receiving the electrical and chemical signals in the brain.

Dendrite
These branching processors receive thousands of incoming signals from other neurons.

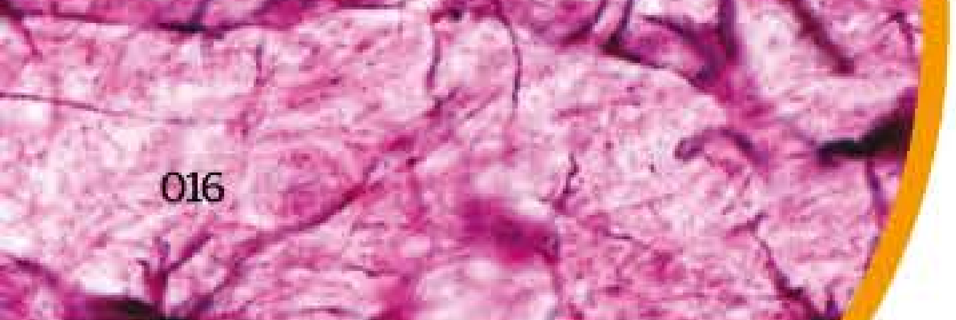
Microglia
These are specialist immune cells that help to keep the brain healthy and free from disease.

Oligodendrocyte
These cells provide insulation, wrapping fatty membranes around the neurons to speed up their electrical signals.

Astrocyte
These star-shaped cells support the neurons, providing nutrients, clearing waste and contributing to signalling.

Axon
This part of the neuron transmits electrical signals towards neighbouring cells.

Synapse
Chemical signals are exchanged at these junctions, passing messages from one neuron to the next.



This microscope image shows astrocytes grabbing on to blood vessels with their 'feet'

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The blood-brain barrier

This biological wall keeps your brain safe and secure

Your brain is arguably your most important organ, and it is vital that it isn't affected by wayward chemicals or aggressive infections. To keep your nerve cells safe, your body builds a biological wall called the blood-brain barrier.

Blood vessels are the highway of the human body, carrying nutrients and oxygen to tissues and taking away waste products, but unfortunately they can also transport harmful chemicals and infections. In most parts of the body, chemicals are able to freely cross through the walls of the blood vessels, leaking between the cells and out into the tissues, but thankfully this does not occur in the brain.

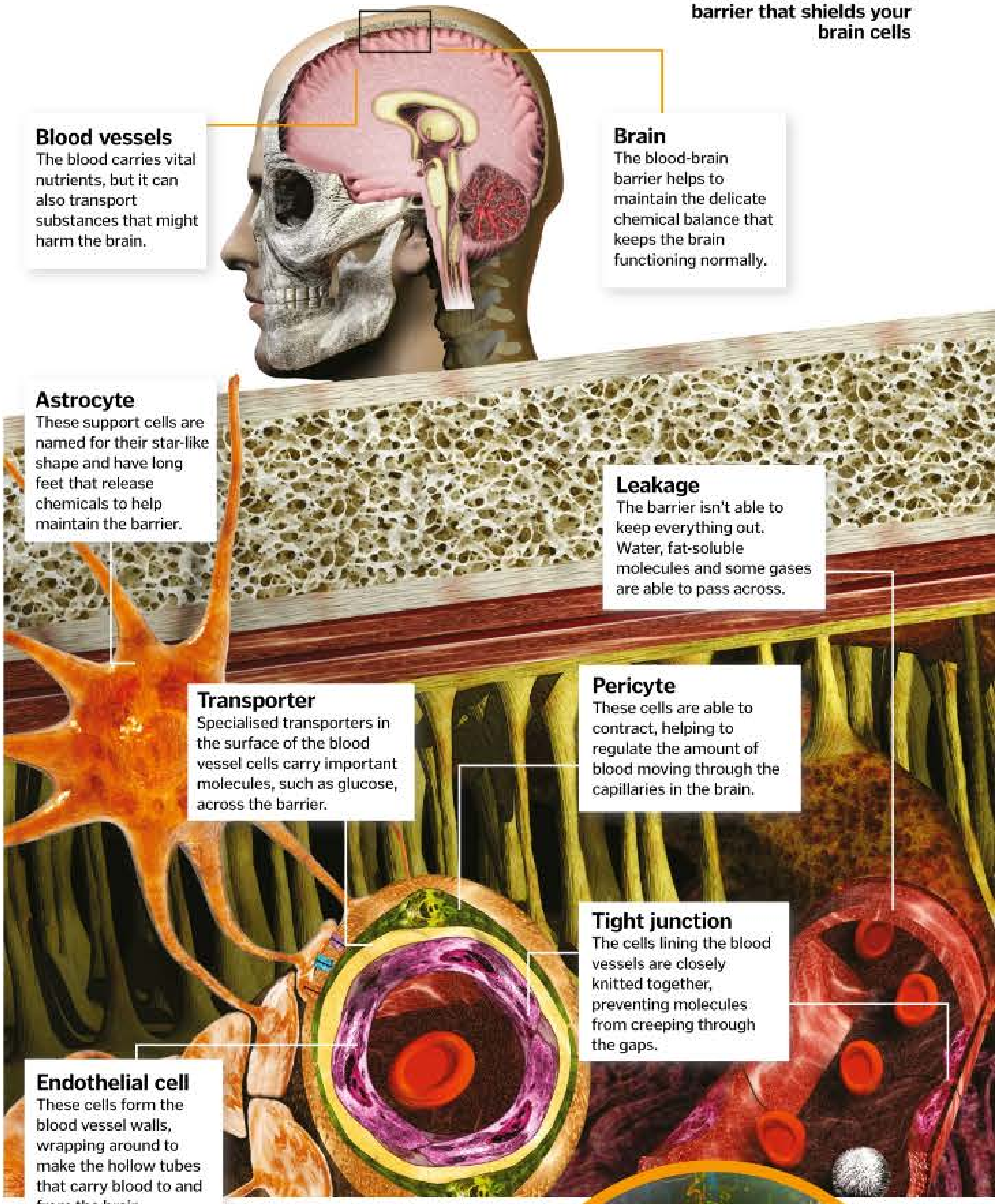
To prevent unwanted contaminants from entering, the cells lining the blood vessels are closely knitted together by structures called 'tight junctions'. Web-like strands pin the membrane of one cell to the membrane of the next, forming a seal that prevents any leakage through the cracks.

Wrapped around these cells are pericytes, which are cells that have the ability to contract like muscle, controlling the amount of blood that passes through the vessels. Just outside the pericytes, a third cell type, the astrocytes, send out long feet that produce chemicals to help maintain the barrier.

Some large molecules, like hormones, do need to get in and out of the brain, and there are areas where the barrier is weaker to allow these to pass through. One such region, called the 'area postrema', is particularly important for sensing toxins. It is also known as the 'vomiting centre', and you can probably guess what happens when that is activated!

Protecting the brain

Take a closer look at the barrier that shields your brain cells



Blood vessels
The blood carries vital nutrients, but it can also transport substances that might harm the brain.

Brain
The blood-brain barrier helps to maintain the delicate chemical balance that keeps the brain functioning normally.

Astrocyte
These support cells are named for their star-like shape and have long feet that release chemicals to help maintain the barrier.

Leakage
The barrier isn't able to keep everything out. Water, fat-soluble molecules and some gases are able to pass across.

Transporter
Specialised transporters in the surface of the blood vessel cells carry important molecules, such as glucose, across the barrier.

Pericyte
These cells are able to contract, helping to regulate the amount of blood moving through the capillaries in the brain.

Tight junction
The cells lining the blood vessels are closely knitted together, preventing molecules from creeping through the gaps.

Endothelial cell
These cells form the blood vessel walls, wrapping around to make the hollow tubes that carry blood to and from the brain.

Crossing the barrier

If nothing could cross the blood-brain barrier, your brain cells would quickly die. In fact, water and some gases pass through easily, and the cells are able to take up important molecules, such as sugars, and pass them across. Molecules that dissolve in fat can also slip through, allowing chemicals like nicotine and alcohol to easily pass into the brain. There is a problem though. Most medicines are too big or too highly charged to cross over, and if a patient has a neurological condition like depression or dementia, treating the brain directly is a real challenge. Researchers are working on ways to breach the barrier, including delivering treatments directly into the fluid around the brain, disrupting the barrier by making the blood vessels leaky, and even designing Trojan horse molecules to sneak treatments across.

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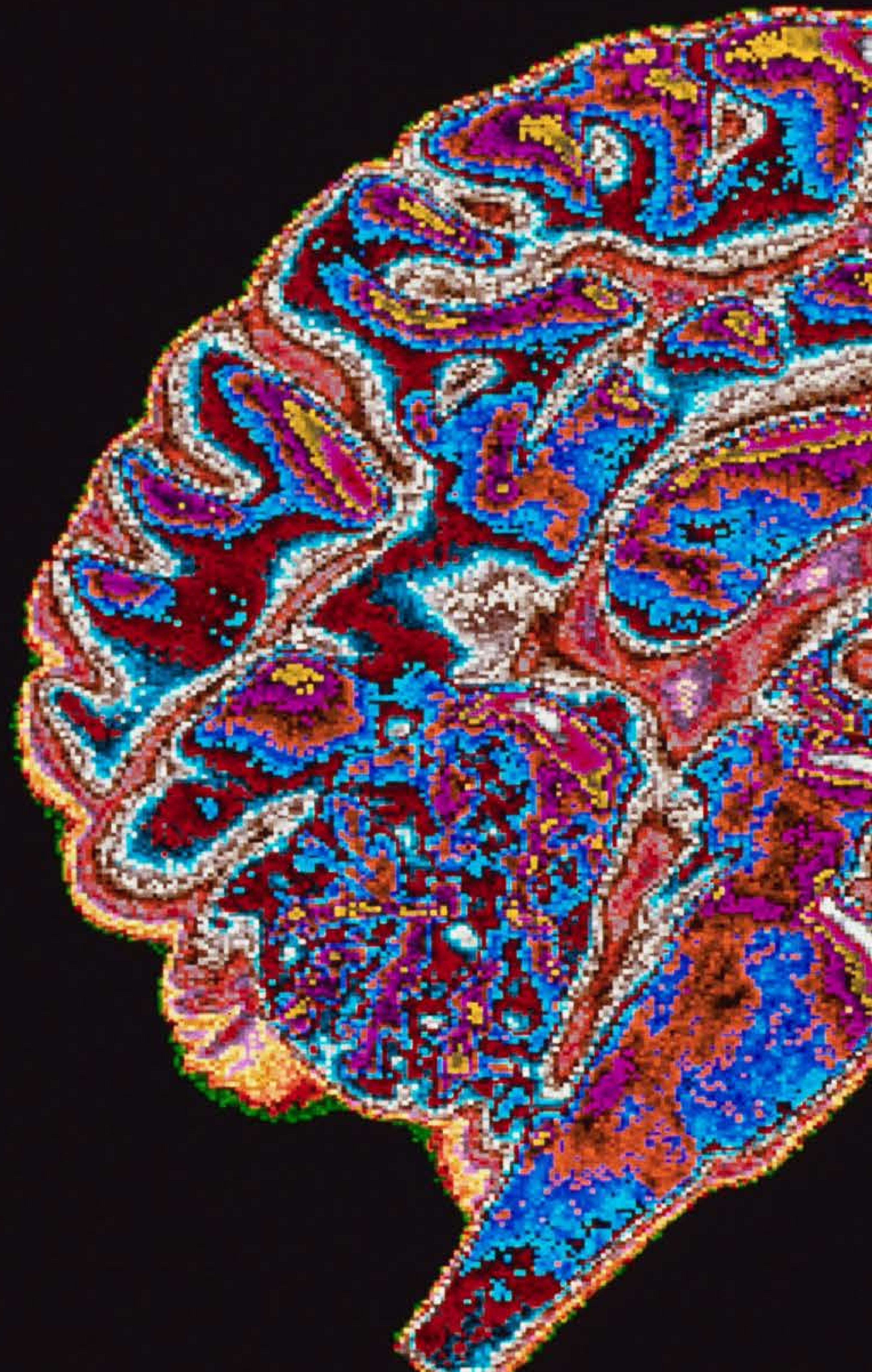
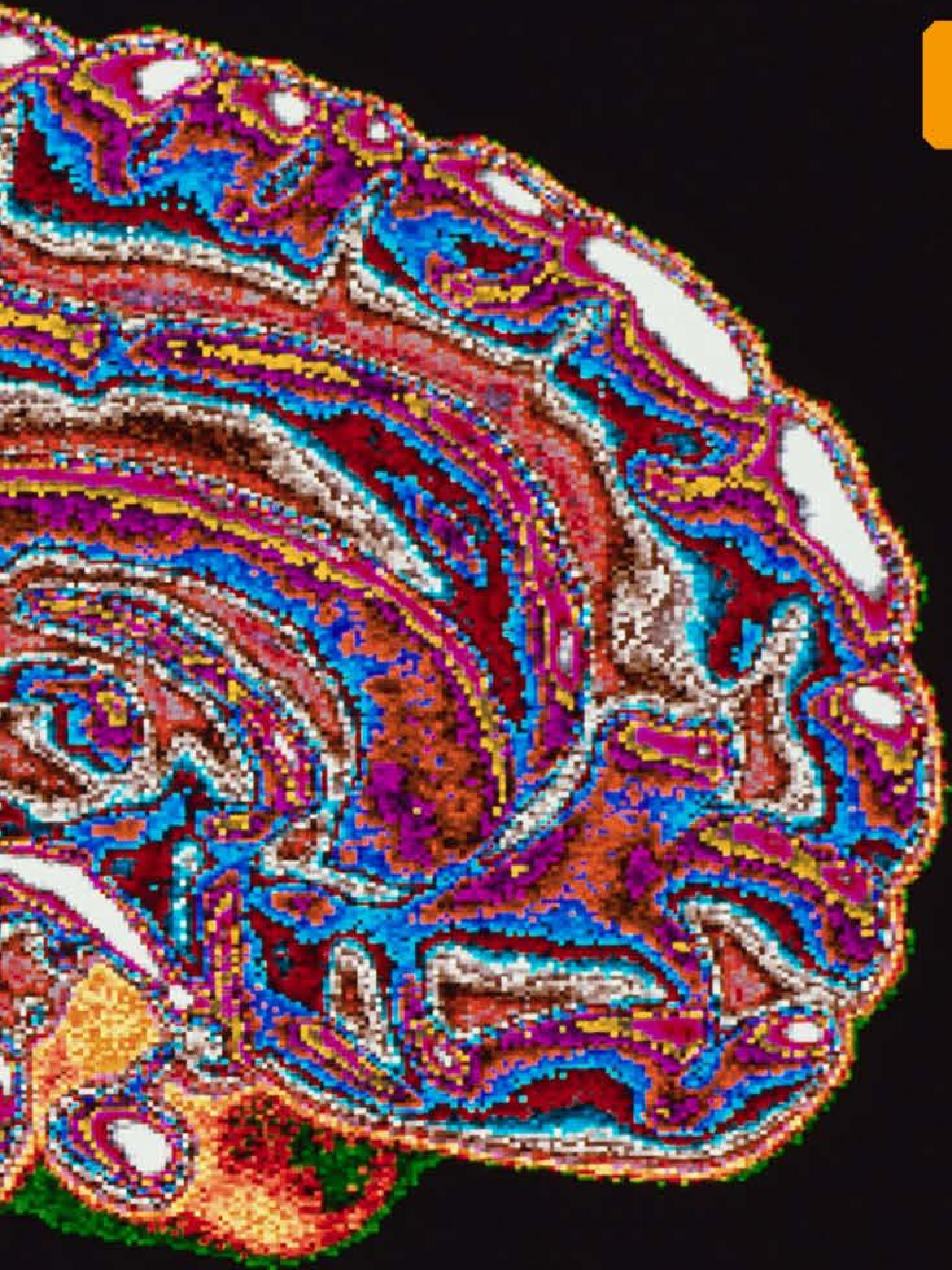




Brilliant brain

This psychedelic photo is a colourful cross-section image of a human brain.

© Getty Images

Pituitary gland up close

What does this hormone factory do and why couldn't we live without it?

The pea-sized pituitary gland is found at the base of the brain, close to the hypothalamus. At a glance, it looks a relatively insignificant part of the brain, but it actually plays a role in many vital systems.

Often referred to as the 'master gland', it not only releases hormones that control various functions, but it also prompts the activity of other glands like the ovaries and testes.

The pituitary gland comprises three sections called lobes: the anterior, the posterior and the intermediate – the latter of which is considered part of the anterior lobe in humans. These work together with the hypothalamus, which monitors hormones in the blood and stimulates the pituitary gland to produce/release the appropriate hormone(s) if levels fall too low.

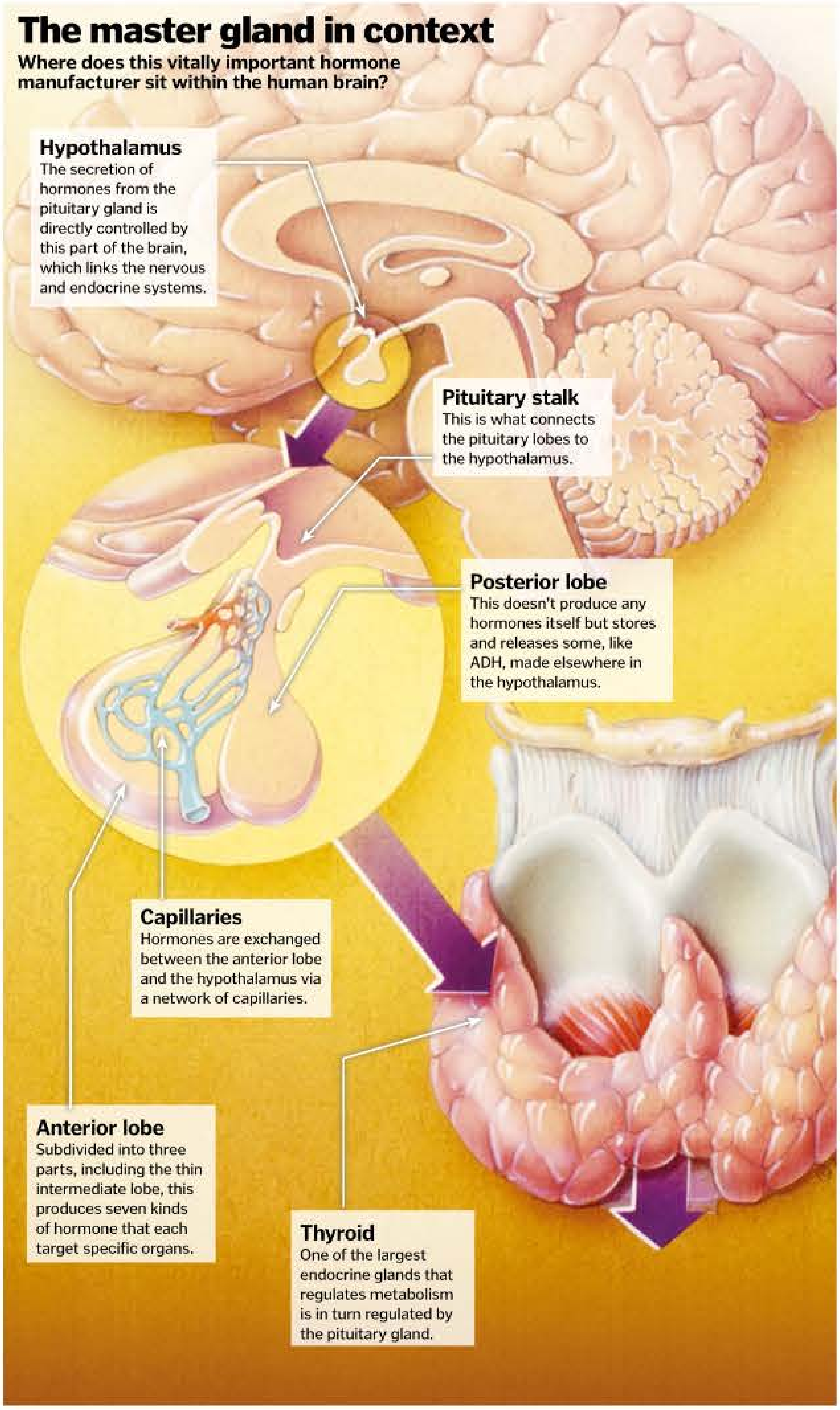
The anterior lobe produces seven important hormones, which include those that regulate growth and reproduction. Adrenocorticotropic hormone (ACTH) targets the adrenal glands to produce cortisol and controls metabolism, while luteinising hormone triggers ovulation in women and stimulates testosterone production in men. The posterior lobe, meanwhile, doesn't generate any hormones itself but stores two: antidiuretic hormone (ADH), which decreases urine production by making the kidneys return more water to the blood, and oxytocin, which tells the uterus to contract during childbirth and also prompts milk production.

Gigantism in focus

The pituitary gland also produces growth hormone, which in adults controls the amount of muscle and fat in the body and plays a key role in the immune system. In children growth hormone has a very noticeable effect in increasing height and bulk until adulthood. However, sometimes the pituitary gland becomes hyperactive – often as a result of a benign tumour – and produces excess growth hormone. In these cases, a person can grow to a far-beyond-average height, with hands, feet and facial features growing proportionally. While this might not seem so bad, gigantism is nearly always accompanied by other health issues, such as skeletal problems, severe headaches and more life-threatening conditions like heart disorders. If diagnosed early, treatment such as drugs that inhibit growth hormone production and surgical removal of the tumour can help avert the more serious conditions of gigantism.

The master gland in context

Where does this vitally important hormone manufacturer sit within the human brain?



Hypothalamus
The secretion of hormones from the pituitary gland is directly controlled by this part of the brain, which links the nervous and endocrine systems.

Pituitary stalk
This is what connects the pituitary lobes to the hypothalamus.

Posterior lobe
This doesn't produce any hormones itself but stores and releases some, like ADH, made elsewhere in the hypothalamus.

Capillaries
Hormones are exchanged between the anterior lobe and the hypothalamus via a network of capillaries.

Anterior lobe
Subdivided into three parts, including the thin intermediate lobe, this produces seven kinds of hormone that each target specific organs.

Thyroid
One of the largest endocrine glands that regulates metabolism is in turn regulated by the pituitary gland.

© Alamy

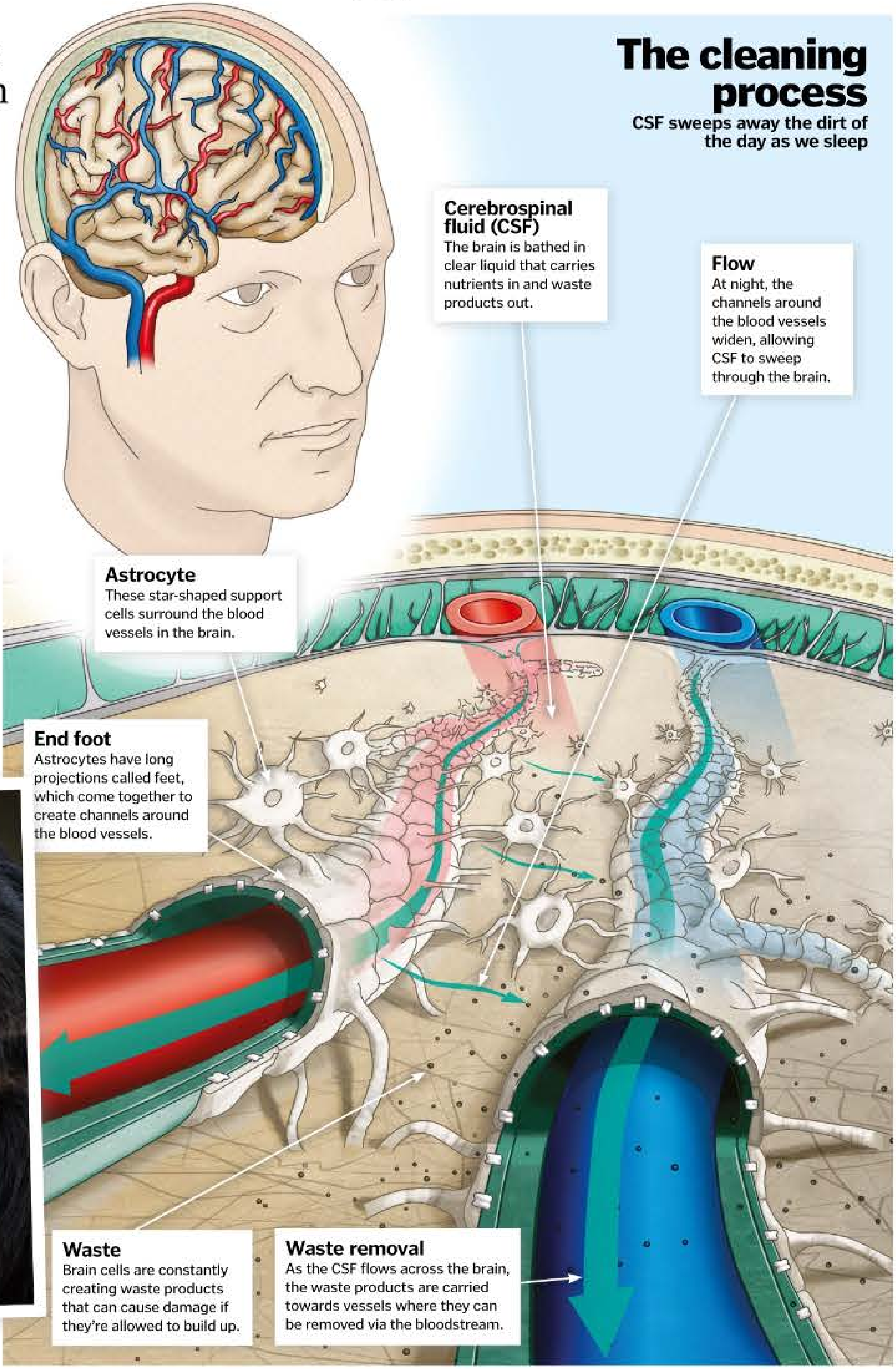
Self-cleaning brains

We have a built-in system to clear toxic waste from between our brain cells

Sleep is one of the brain's great mysteries, but research has revealed an intriguing night-time cleanup system.

The brain is shielded by a barrier made and maintained by cells called astrocytes. They hug the blood vessels, controlling what's allowed in and out, and a space between the vessel wall and these cells seems to play a crucial role in keeping the brain clean.

At night, the astrocytes relax their grip and the space fills up with a clear liquid called cerebrospinal fluid (CSF). It's pushed along by the movement of the blood vessels underneath, swishing up through the astrocytes and out into the spaces between brain cells. As it passes, it picks up waste and debris, carrying the particles back towards the bloodstream so they can be removed from the brain.



The cleaning process

CSF sweeps away the dirt of the day as we sleep

Cerebrospinal fluid (CSF)
The brain is bathed in clear liquid that carries nutrients in and waste products out.

Flow
At night, the channels around the blood vessels widen, allowing CSF to sweep through the brain.

Astrocyte
These star-shaped support cells surround the blood vessels in the brain.

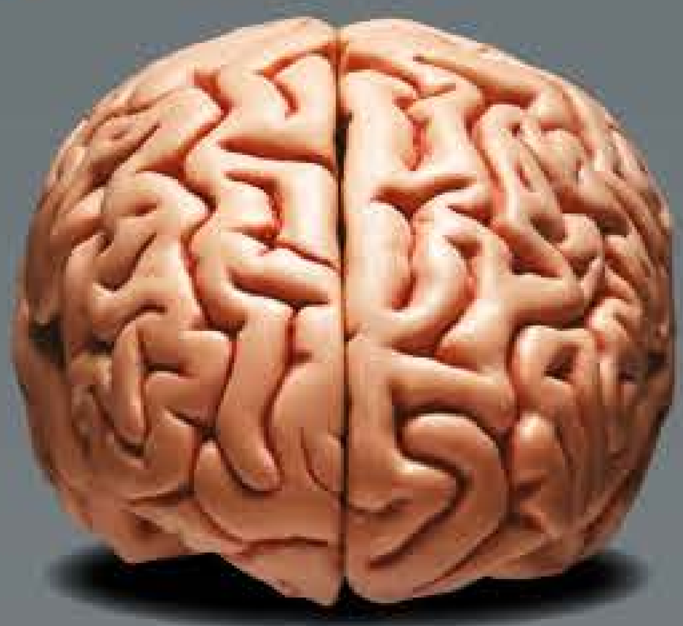
End foot
Astrocytes have long projections called feet, which come together to create channels around the blood vessels.

Waste
Brain cells are constantly creating waste products that can cause damage if they're allowed to build up.

Waste removal
As the CSF flows across the brain, the waste products are carried towards vessels where they can be removed via the bloodstream.

Humans are not alone in possessing CSF; all vertebrates – including chimps – do

© Illustration by Art Agency/Nick Sellers



THE SCIENCE OF EMOTIONS

How our ancient brains evolved the perfect way to keep us safe by controlling the chemicals in our minds to moderate our behaviour

Words by **Charlie Evans**

How are you feeling right now? Are you relaxed laying on your sofa and listening to the gentle sounds of the dawn chorus outside your window? Or maybe you are tense with your shoulders hunched up around yourself as you try to get five minutes peace in a busy office? You would think that it is easy to work out if we are happy or sad, angry or calm, but humans cycle through such a vast array of emotions throughout their lives it can be difficult to distinguish them from one another.

Emotions are not a simple experience. Every time you feel something your body initiates a physiological change, a chemical release and a behavioural response. This process involves multiple processes working together, including your major organs,

© Getty

neurotransmitters and limbic system. Your limbic system is the most primordial part of your brain, thought to have first evolved in early mammals. It's filled with ancient neural pathways that activate our emotions in response to stimuli and controls our fight-or-flight response through the autonomic nervous system.

This response evolved from a need to make decisions based on our emotions. As our body fills with adrenaline and our heart starts racing we prepare to react. Do we stay to fight the bear that has come scavenging for food, or do we flee to somewhere safe? We can still feel the effects of this response. When we are confronted for not doing the dishes we might feel the same fight-or-flight response as our adrenaline starts to flood our system. Our heart rate and breathing increases, the fine hairs on our arms might stand on end, and our hands feel clammy as we decide if we are going to stay and argue or if we are going to escape to to safety of our bedroom.

The biological sensations in our bodies in response to emotions can feel very similar to one another. Imagine your palms sweating, feeling your cheeks warm as they flush red, and your heart pounding in your chest. You could feel this because you are sitting nervously in the dentist's waiting room, or you could be excited as you wait to see your loved ones after they return from a holiday – the physiological reaction is the same. The interpretation of emotions is our logical brain rationalising these responses and describing them as feelings. We take into consideration the context and label our emotions accordingly. However, we don't all do this the same way. Because our bodies cause different floods of chemicals in response to different environmental triggers, each person naturally reacts to situations differently.

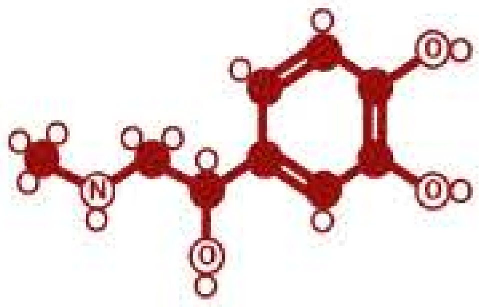
Have you ever seen someone who is being berated in a meeting but facing the onslaught with nothing more than a slightly raised eyebrow? Or watched as someone finds out some bad news but keeps their composure? You are sure that you would have raised your voice or burst into tears, but our responses are defined by how our neurons are

> "We feel our emotions, and not just in our head and heart – our bodily state changes to react to the chemical storm in our system"

The chemistry of emotions

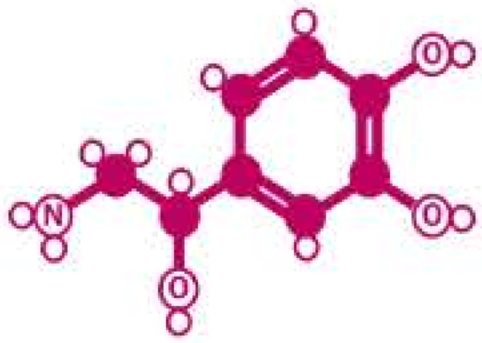
Where two neurons meet, a very small gap (synapse) exists between them. The electrical impulse travelling along the axon of the neuron must convert into a chemical signal to bridge this gap. The chemicals that do this are called neurotransmitters. These so-called chemical messengers are involved in our different responses to situations.

Your emotions depend on fluctuating levels of neurotransmitters, which cause the activation of different parts of the brain responsible for different moods, or activate parts of the brain that trigger the stimulation of the autonomic nervous system.



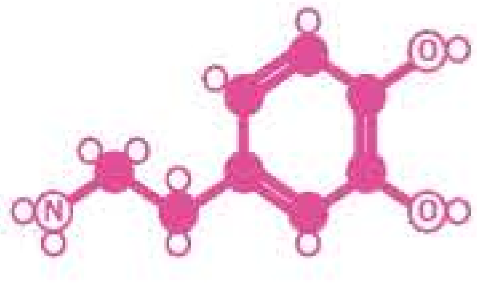
Adrenaline

Released by the adrenal glands that sit on top of each kidney, adrenaline increases the flow of blood to our muscles, raises our heart rate and dilates our pupils. It is crucial in our fight-or-flight survival response.



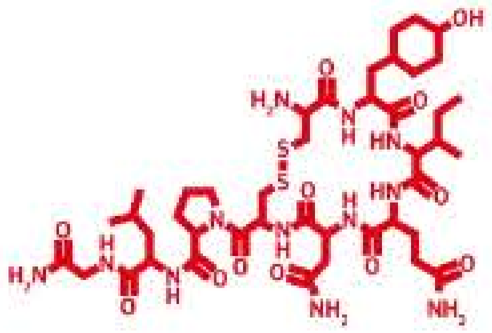
Noradrenaline

Similar to adrenaline, the release of this chemical can result in increased levels of alertness, helping to prime us for action if needed. It also increases our blood pressure and widens our air passages.



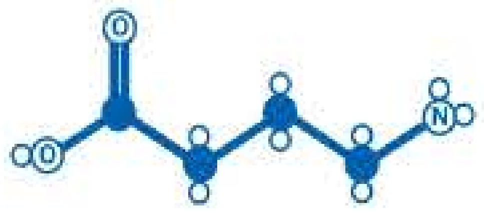
Dopamine

This is the addictive reward chemical that your brain craves. It serves to motivate you to seek out the things you need for your survival. We can sometimes find ourselves enslaved by this ancient reward mechanism.



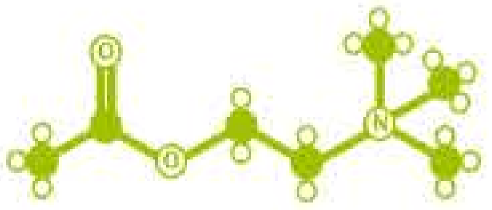
Oxytocin

Also known as the 'cuddle hormone', oxytocin is released when you're close to another person. It's essential for making strong social bonds, and it's also a key part of why we want to trust people.



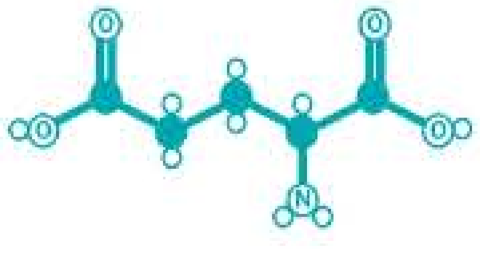
GABA

Responsible for regulating muscle tone, gamma-Aminobutyric acid (GABA) also regulates the communication between brain cells. It can calm us down by reducing the rate at which our neurons fire.



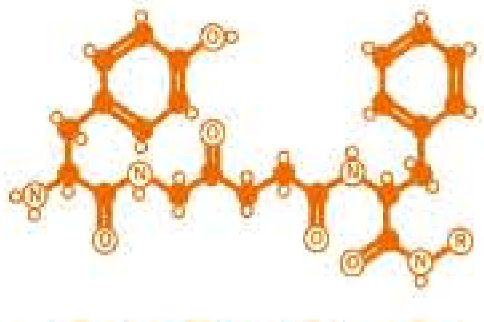
Acetylcholine

This is the main neurotransmitter in the parasympathetic nervous system that slows our heart rate, contracts smooth muscles, dilates blood vessels and increases bodily secretions.



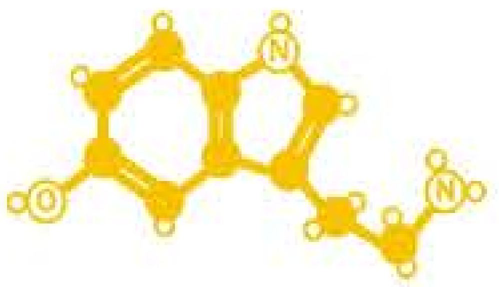
Glutamate

The most abundant neurotransmitter in the vertebrate nervous system, glutamate is used by nerve cells to transmit signals to other cells. Too much of it can cause cognitive impairments.



Endorphins

Triggered by the sensation of pain, endorphins work to inhibit the transmission of pain signals. Capable of producing a sense of euphoria, studies have suggested endorphins may also be stimulated by laughter.

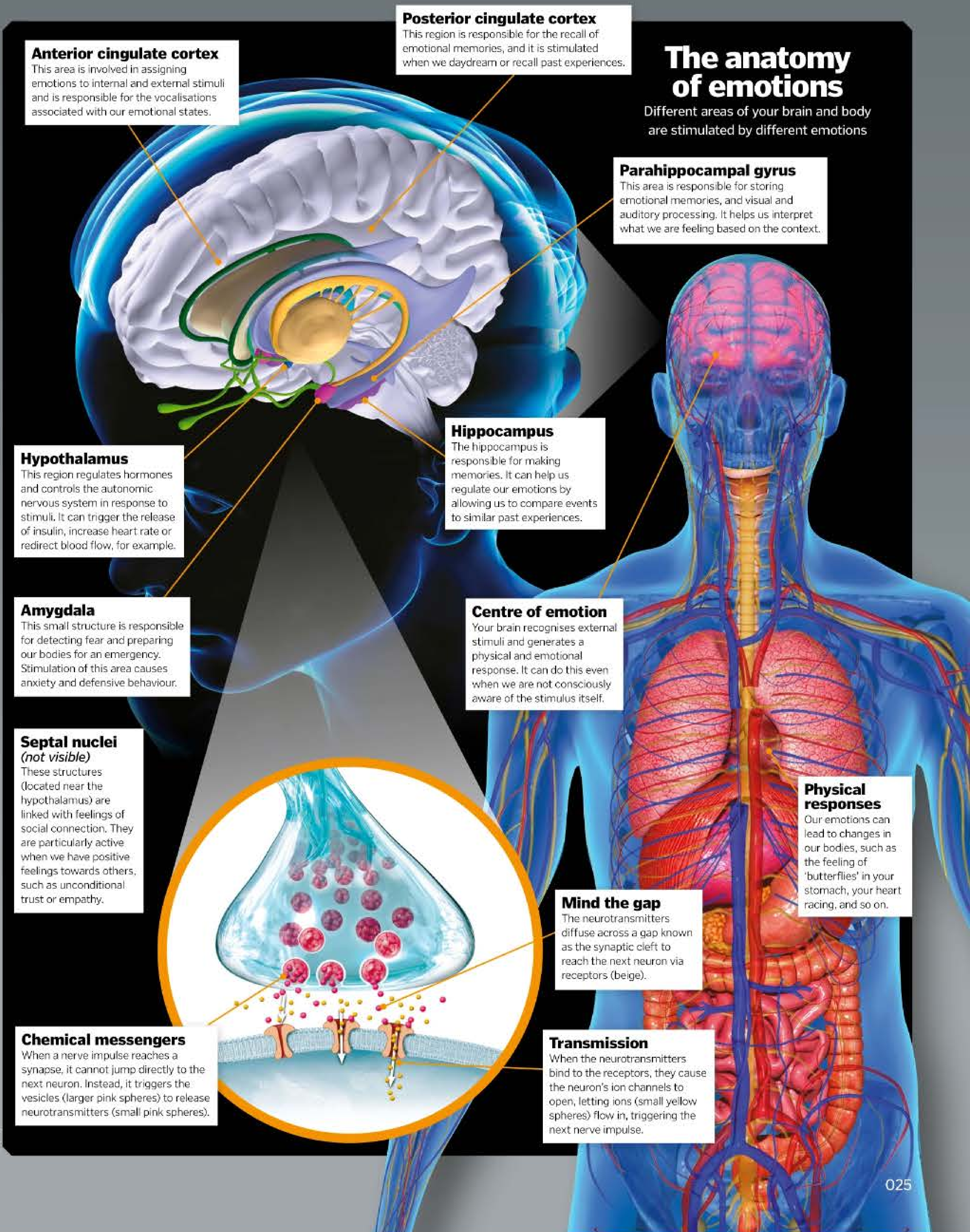


Serotonin

Serotonin is linked to our wellbeing and happiness, and our levels of it are affected by exercise and exposure to sunlight. It also helps to regulate our mood balance, sleep cycle and digestion.

The anatomy of emotions

Different areas of your brain and body are stimulated by different emotions



Anterior cingulate cortex
This area is involved in assigning emotions to internal and external stimuli and is responsible for the vocalisations associated with our emotional states.

Posterior cingulate cortex
This region is responsible for the recall of emotional memories, and it is stimulated when we daydream or recall past experiences.

Parahippocampal gyrus
This area is responsible for storing emotional memories, and visual and auditory processing. It helps us interpret what we are feeling based on the context.

Hypothalamus
This region regulates hormones and controls the autonomic nervous system in response to stimuli. It can trigger the release of insulin, increase heart rate or redirect blood flow, for example.

Hippocampus
The hippocampus is responsible for making memories. It can help us regulate our emotions by allowing us to compare events to similar past experiences.

Amygdala
This small structure is responsible for detecting fear and preparing our bodies for an emergency. Stimulation of this area causes anxiety and defensive behaviour.

Centre of emotion
Your brain recognises external stimuli and generates a physical and emotional response. It can do this even when we are not consciously aware of the stimulus itself.

Septal nuclei
(not visible)
These structures (located near the hypothalamus) are linked with feelings of social connection. They are particularly active when we have positive feelings towards others, such as unconditional trust or empathy.

Physical responses
Our emotions can lead to changes in our bodies, such as the feeling of 'butterflies' in your stomach, your heart racing, and so on.

Mind the gap
The neurotransmitters diffuse across a gap known as the synaptic cleft to reach the next neuron via receptors (beige).

Chemical messengers
When a nerve impulse reaches a synapse, it cannot jump directly to the next neuron. Instead, it triggers the vesicles (larger pink spheres) to release neurotransmitters (small pink spheres).

Transmission
When the neurotransmitters bind to the receptors, they cause the neuron's ion channels to open, letting ions (small yellow spheres) flow in, triggering the next nerve impulse.

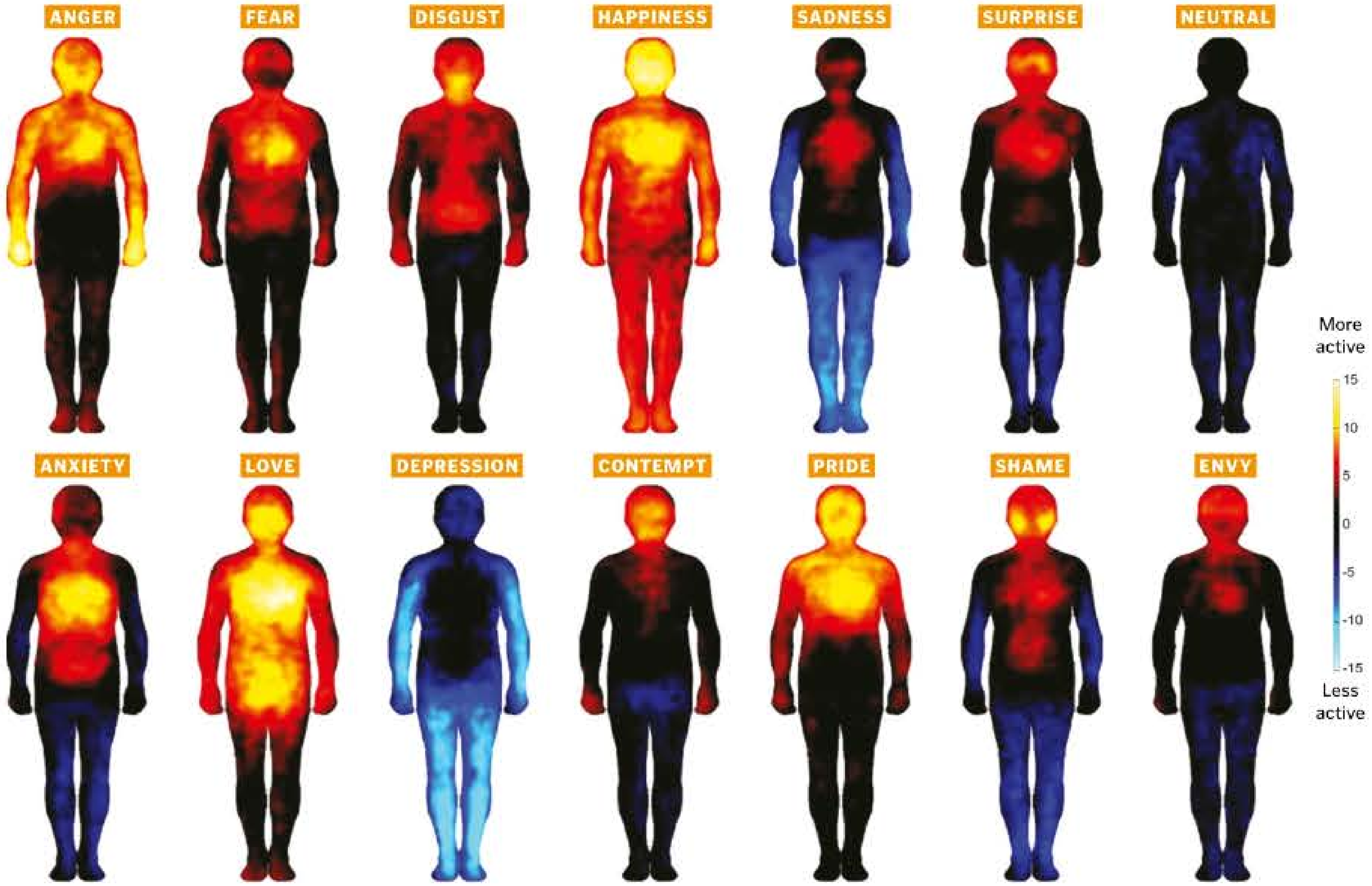
© Getty

The chemicals released when we're close to our family help us to build trust and closeness

networked together. Our past experiences and genetic predispositions influence our brain chemistry and therefore our physiological responses, which in turn determine how we react to various situations – like someone cancelling on us last minute, or having a friend surprise us by showing up at the front door unannounced.

At times our emotions can seem like an irrational response, but our brains have carefully evolved these mechanisms with just one target – keeping us alive. While we interpret different emotions as positive or negative, the most ancient parts of the human brain developed them on the principle that we must survive. We evolved emotions as a means of communicative function and to help us navigate social interactions and our environment safely: they are designed to protect us. Our fear responses were originally a survival tactic that warned us of potential dangers, such as our innate unease around spiders and snakes. Then there is the feeling of disgust, which warns us of foods or other substances that may be dangerous.

Our other emotions are responses to social interactions that keep us part of a group. We are fundamentally a social species, and throughout our evolution have relied on our tribe to help us survive by working together to find food and shelter. Anger is a response to perceived social threats or a signal of dominance, pride can help us to boost our social status, while shame is intended to decrease our standing within a group. These emotions maintain the social balance of our



Emotions as sensations

We feel our emotions, and not just in our head and heart – our bodily state changes to react to the chemical storm in our system. We might feel a tight knot in our stomach as we dread walking onto a stage to give a speech, or we might feel our cheeks flush red when we answer a question wrong.

Researchers from Aalto University in Finland explored how humans physically feel their emotions by mapping the sensations topographically. Their findings were consistent across Western European and East Asian cultures, which suggests the way people feel during an emotional experience stems from a biological source rather than a cultural interpretation. The study also highlighted that emotions adjust our bodily state to either prepare ourselves physically to fight or flee or to encourage us to seek out enjoyable social reactions.

The study included over 700 participants from Finland, Sweden and Taiwan, and researchers induced different emotional states before asking them to colour bodily areas on images of the human body to describe in which areas they felt activity increasing or decreasing.

tribe – who we follow, who we trust, who we care about.

The fundamental emotions that motivate us individually are almost always sadness and happiness. Sadness results from loss and serves the biological purpose of motivating a person to recover that loss, whether it is a young child searching for their mother in a supermarket, or trying hard to get a new job after being dismissed. But the ultimate human emotion is happiness, and we are all in search of it.

When you're sitting around a campfire, safe in the countryside with some close friends and good food, you feel happiness because you have found the resources that your primitive brain is seeking. Our species is drawn so much to happiness because this emotion is our brain's reward system for finding environments where we are free from threat. A healthy human brain copes with sadness when social bonds are broken, communicates with our loved ones and can recognise and regulate our emotions even when they do not feel particularly positive.

The emotional mechanisms in our bodies evolved to keep us safe and connect us with others

The next time you sit in an airport departure lounge, look for the emotions. Our bodies have created these experiences – the tears as we say goodbye, the smiles and laughter as we are reunited – for the purpose of keeping us alive. Our emotions and feelings are fundamentally what make us human, but it means we're in for a bit of a rollercoaster along the way.

> "Reading the emotions of others is a vital skill for navigating our way through life"

Universal expressions

Reading the emotions of others is a vital skill for navigating our way through life – it would be awkward to misunderstand your friend as happy when they're actually angry with you.

There has been a long-established view that the way we express our feelings using our facial expressions is universal and crosses all cultures for seven basic emotions: anger, disgust, fear, joy, sadness, surprise and contempt. For over a century, studies have explored the theory of universal expression by asking people to interpret photographs displaying various emotions, although there are some cultures around the world that do not have the same perception of certain emotions.

One study found that people living in the Trobriand Islands off Papua New Guinea didn't interpret images of people who were wide-eyed with their lips parted as they gasped as a sign of fear. Instead, the Trobrianders interpreted this emotion as anger. This research is some of the first to suggest that how we express our emotions is not universal, and may differ between societies.

While the expression of happiness and sadness is generally the same all over the world, surprise and fear can be interpreted differently between cultures

How many emotions do we have?

It has long been thought that there are only six different emotions: anger, disgust, fear, happiness, sadness and surprise. It has been hypothesised that any other emotions are just a combination of these basic feelings, such as anticipation being caused by a mixture of fear and happiness. However, a recent study published in *Proceedings of the National Academy of Sciences of the United States of America* from researchers at UC Berkeley suggests that we may have many more emotions that are distinctively different to one another, but still related.

The study used 2,185 short videos with the intent to evoke emotions in the 853 participants. Clips included a cute baby playing with some fluffy puppies, a man holding a tarantula inside his mouth, and a happy couple getting married. Participants were asked to record how the videos made them feel and how strongly it evoked a response. The study suggests that there are 27 distinct emotions, including awe, awkwardness, calmness, confusion, disgust, nostalgia, sadness, sympathy, horror and triumph.

We may have more emotions than we are able to express in our languages

© Getty ; Nummenmaa et al/Aalto University

Memory and retaining information

We take it for granted, but how do we retain and utilise information from our environment?

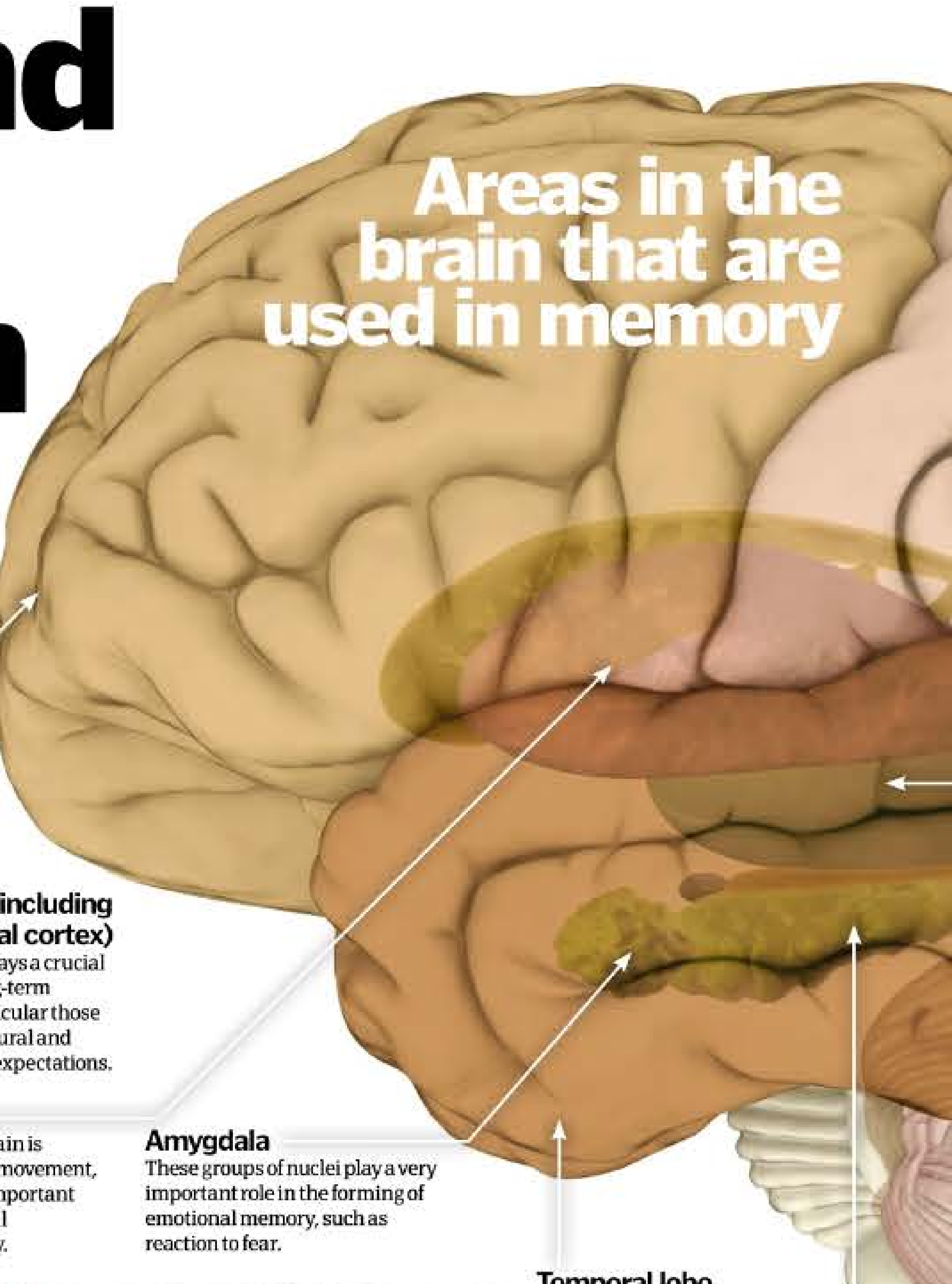
Memory is the capacity to store and retain information, then recall it for use when needed. It is used by most organisms to operate in the most successful manner they possibly can in their unique environment.

There are three main types of memory: sensory, short-term and long-term, although long-term is often split into different types of memory. Sensory memory is a very short-term type of memory that is evoked through the senses. It lasts for a few seconds at most and is not stored.

Short-term memory is a slightly longer-lasting form – around 20 seconds. It's the recording of memories currently being used – i.e. remembering a number to dial in the next 30 seconds. If the information is repeated, however, it causes pathways to form between neurons in the brain and a phrenological loop to be created, causing a memory to be stored as a long-term memory. Unless this repeated firing of the neurons occurs, which is forced by repeating the information, a memory is lost.

When we cannot remember something, it's generally not because of developing a degenerating brain disease like Alzheimer's – it's far more likely to be that the correct stimuli have not been presented to prompt retrieval of the memory, or that you did not register or retain the original information properly. For example, if you cannot remember where you put your shoes when you took them off, it may be that you were not paying attention when you put them down and consequently have not transferred the memory from short-term to long-term in the first place, rather than having forgotten.

As long as you have registered and retained the event, correct stimuli would cause a refiring of the neurons when creating the original memory, allowing successful retrieval of the information required. Dependent on its type, a memory is stored in different areas of the brain. This helps people to store related information more easily, as it can be linked to previously stored related material.



Areas in the brain that are used in memory

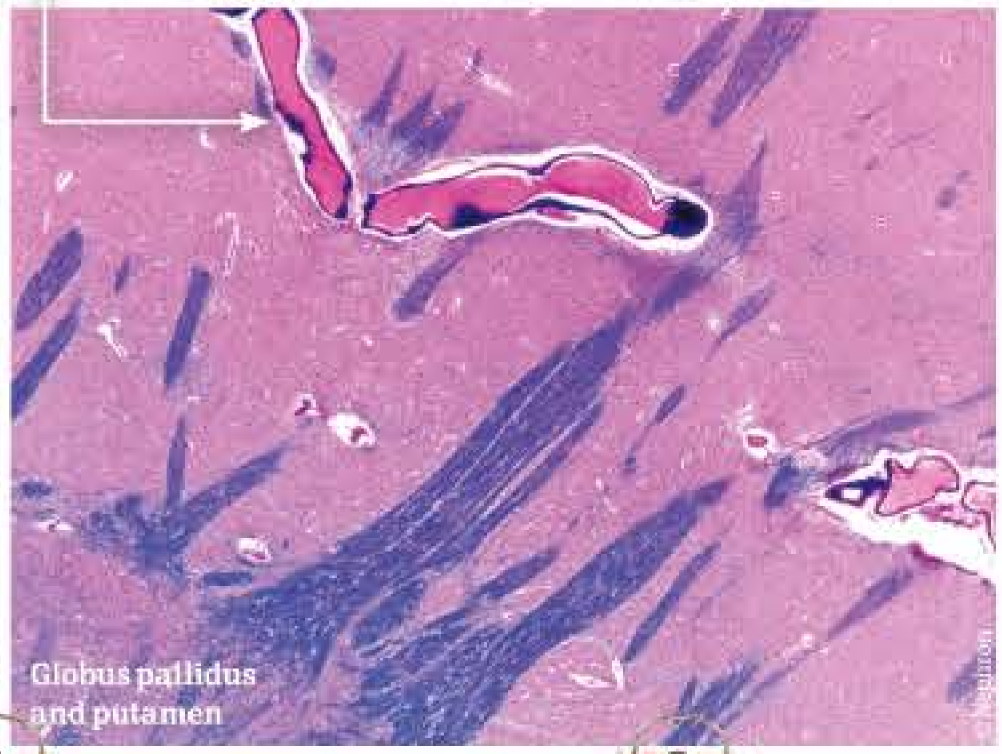
Frontal lobe (including the pre-frontal cortex)
The frontal lobe plays a crucial role in storing long-term memories, in particular those related to behavioural and social norms and expectations.

Putamen
This area of the brain is very important in movement, therefore it is an important area for procedural long-term memory.

Amygdala
These groups of nuclei play a very important role in the forming of emotional memory, such as reaction to fear.

Temporal lobe
This lobe of the brain primarily stores and processes auditory information and therefore plays a particularly important role in speech and language. The hippocampus sits within the temporal lobe.

Hippocampus
The hippocampus is one of the crucial parts of the brain for the transferal of short-term memories into the long-term. Damage to this area will hinder an individual's ability to make new memories.



Globus pallidus and putamen

How we form and store long-term memories

The time it takes for a memory to really stick

Attention

0.2 secs

If something grabs our attention we're far more likely to remember it. Neurons fire as we continue to focus, ensuring a memory moves from short-term to long-term. The thalamus plays a big role in directing attention.

Emotion

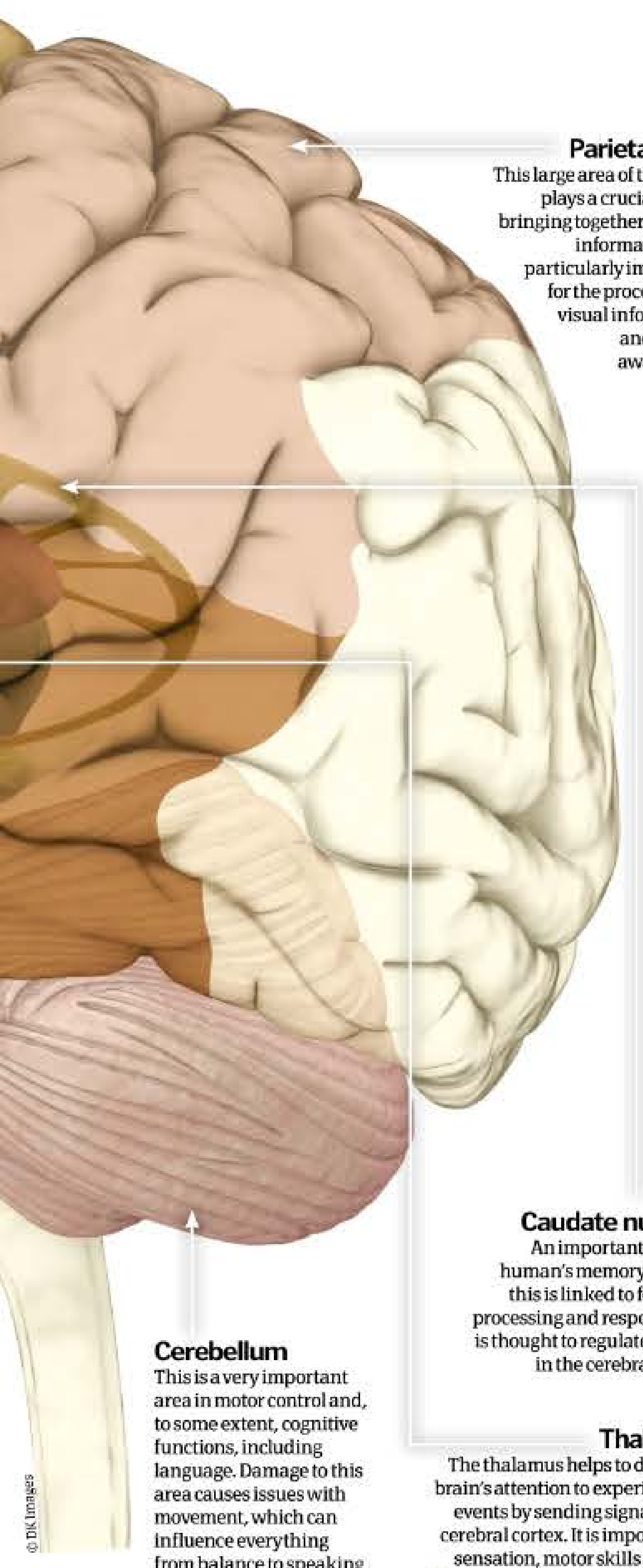
0.25 secs

Events or things that cause an emotional response are more likely to be remembered because they activate raised levels of activity in the amygdala, and this arousal means more information is taken in and processed.

Sensation

0.2-0.5 secs

Sensory memory is based on receiving information from our senses – i.e. sight, smell, touch. The lingering feeling you have after someone touches your arm is the sensory memory fading, and this first information from the senses is the starting point for any memory.



© DK Images

Parietal lobe
This large area of the brain plays a crucial role in bringing together sensory information. It is particularly important for the processing of visual information and spatial awareness.

Caudate nucleus
An important part of a human's memory system, this is linked to feedback processing and response and is thought to regulate activity in the cerebral cortex.

Cerebellum
This is a very important area in motor control and, to some extent, cognitive functions, including language. Damage to this area causes issues with movement, which can influence everything from balance to speaking and walking.

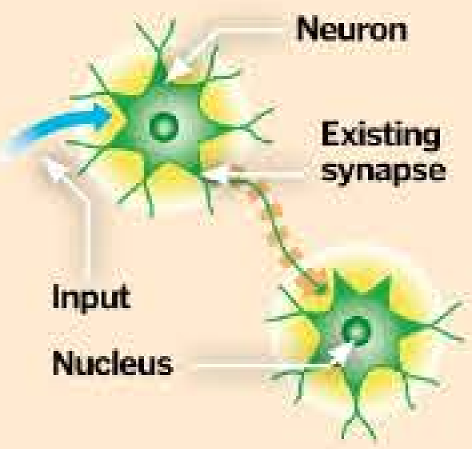
Thalamus
The thalamus helps to direct the brain's attention to experiences or events by sending signals to the cerebral cortex. It is important for sensation, motor skills and also helps to regulate sleep.

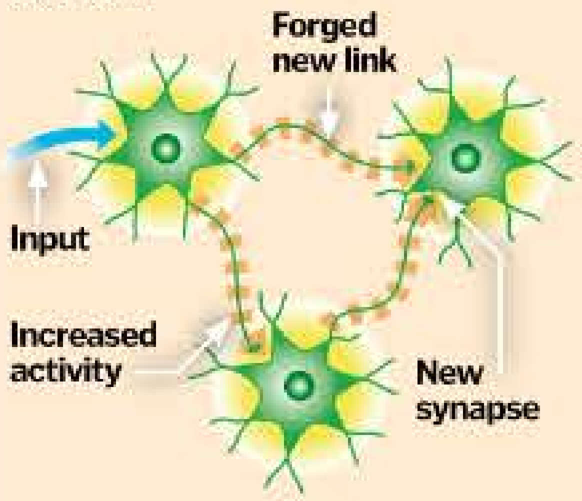
How do we store memories?

Memories are formed in our brains through electronic pulses passing between neurons. As neurons fire more than once, the pathway and link between the neurons strengthens; if the first neuron is triggered in the future, it is more likely that the others will too. Memories are stored in different areas of the brain, depending on what they are and what they are used for.

Input

The stimulus for a memory can be nearly anything. It can be related or unrelated. For example, if you see a letterbox, you may remember you had a letter to post, therefore stimulating a memory through a related input. However, some people use unrelated stimuli, like a piece of string tied to their finger, which they have formed an unrelated link to something else with.



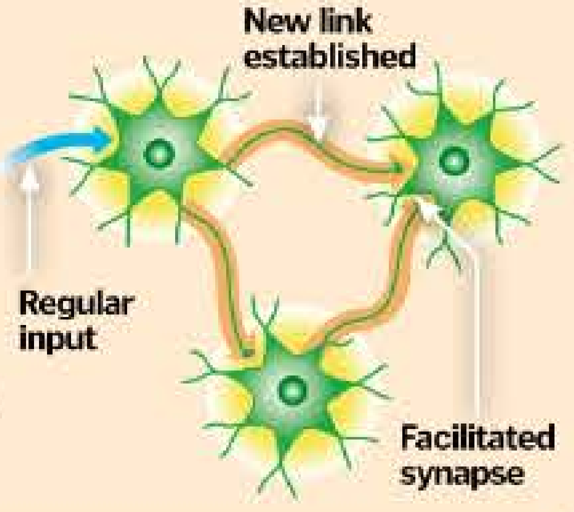


Circuit formation

As a memory is being formed, certain neurons will link together in a circuit to store this memory. It will link related memories, and repetition of this circuit firing will strengthen the memory. This is called a phrenological loop.

Increasing activity

Repeated firing of the neurons involved in the first memory formation (repetition to remember) will strengthen the memory, as the neuron pathway becomes stronger and the memory can be retrieved and utilised faster.



Types of memory

The complex ways we remember…

Sensory memory

Sensory memory is evoked through the senses and is the initial perception of something. This is a fleeting memory and will not be transferred into short- or long-term unless we focus on remembering the event.

Short-term

This type of memory is stored temporarily for up to 20 seconds. It can, however, be confused with working memory, a separate type of memory that allows an individual to retain information only for long enough to, say, complete a sum. Unless information is repeated several times to establish a pathway between neurons it will decay and be lost.

Long-term – procedural (implicit)

This kind of long-term memory is how we remember to do things such as ride a bike. It is where we store our 'body' memories – our motor skills.

Long-term – declarative (explicit)

This type of memory is how we store facts for retrieval and consists of things such as names and dates.

Long-term – episodic

This is where we store event-related memories and link them together. For example, if you went to a dinner party you wouldn't remember every moment, but you would recall a collection of events, smells and sounds that link together when you think of the overall event.

0.5 secs - 10 mins

Working memory

Working memory is when information is briefly stored in order to be used in the immediate future. It lasts for a few seconds or so, but if repetition occurs, refreshing the time limit in which it can survive, it will be retained and can move into short- or long-term.

10 mins - 2 years

Hippocampal processing

If we need to retain a piece of information, or it particularly strikes us, it will travel from the short-term memory, based in the pre-frontal cortex, then to the hippocampus, where it is processed and can move into the long-term memory.

2 years +

Consolidation

If you use a piece of information repeatedly, the links between the neurons remain strong. These are likely to stay in place for a long time. Although the pathways between neurons are changing as we receive, process and retain new information, repetition and reuse can cause the pathways to remain and the memory to stay in the brain.

BRAINPOWER

032 Power of imagination
The biology behind your imagination and how dreaming things up has helped our species

036 How the brain sees
What you see through your eyes isn't the same as the image that your brain receives

038 Facial recognition
We may take our skill at identifying faces for granted, but it's a vital ability

042 Anticipatory timing
Find out how your brain 'predicts' the future

043 Decision-making
Do we all really have free will?

044 Fight or flight
How your brain keeps you alive in an emergency

038

042

044

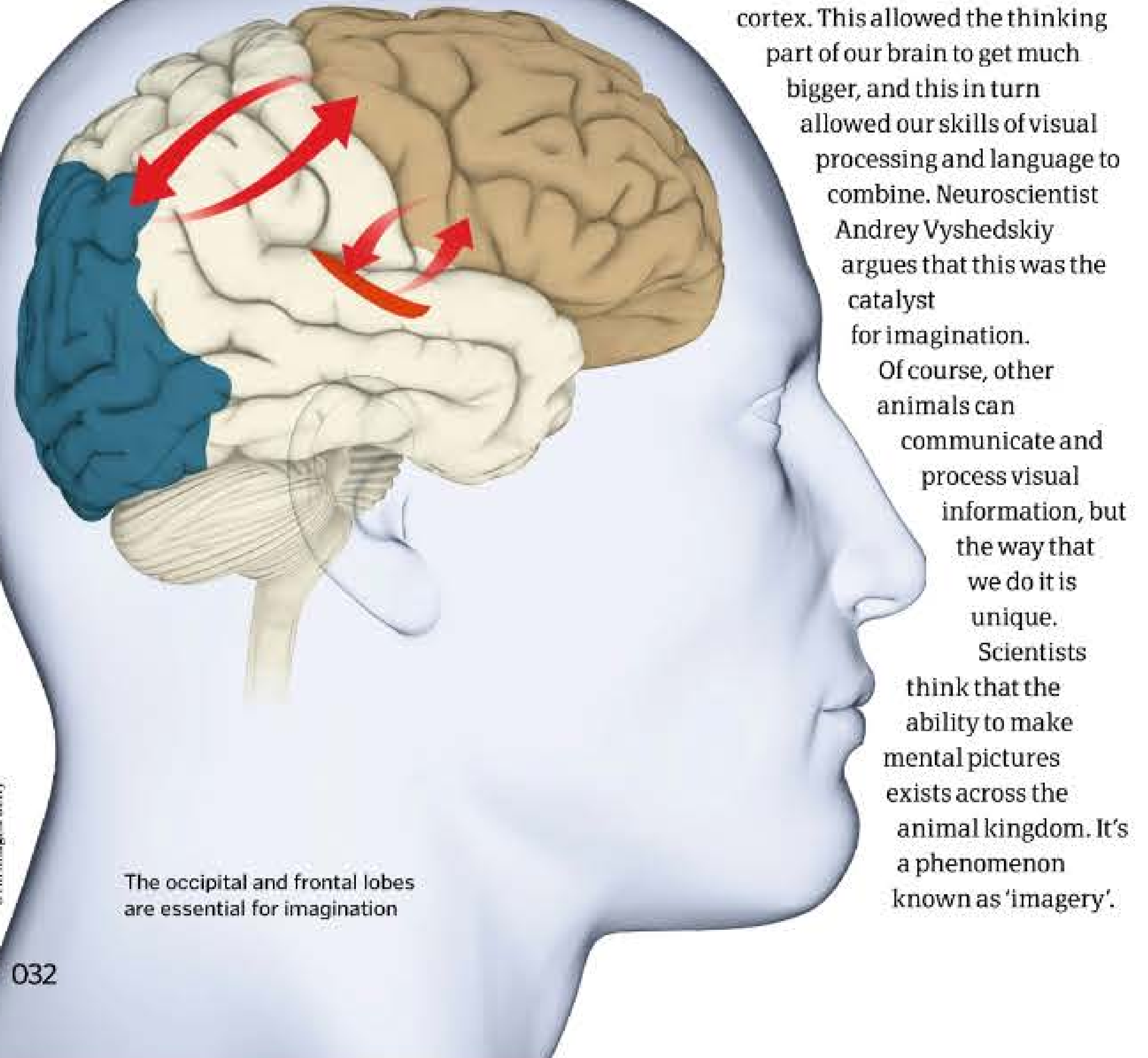
THE POWER OF IMAGINATION

The human brain has the unique ability to take what it knows and dream up something new

Words by **Laura Mears**

Can you imagine a purple dragon riding a bicycle with three wheels? No other animal on the planet has that power. You have the ability to take mental images of objects you've seen before, break them down into their component parts and rebuild them into something new.

Combine a reptile and a bird and you have your dragon. Recall the purple colour of a flower and you can paint its skin. Think about the mechanics of riding a bicycle and you'll be able to position its body on the frame, forelegs on the handlebars, hindlegs on the pedals. Now you just need to decide where you want to put that third wheel. This skill is incredible, and it's shaped the course of human history. Culture, engineering, art, science, music, technology: these things are only possible because we can make things up. But the ability to imagine hasn't always been there.



The occipital and frontal lobes are essential for imagination

© All images: Getty

When modern humans first started migrating out of Africa around 100,000 years ago, they were still using the same simple tools as their ancestors. It was another 60,000 years before human creativity really started to explode.

Between the emergence of modern humans and the 'creative explosion', mutations in our genes slowed down the development of the brain's processor, the prefrontal cortex. This allowed the thinking part of our brain to get much bigger, and this in turn allowed our skills of visual processing and language to combine. Neuroscientist Andrey Vyshedskiy argues that this was the catalyst for imagination.

Of course, other animals can communicate and process visual information, but the way that we do it is unique.

Scientists think that the ability to make mental pictures exists across the animal kingdom. It's a phenomenon known as 'imagery'. But it's not the same as imagination. Take bicycles, for example. When we see a bicycle, networks of neurons fire in the visual processing regions of our brains. To store a memory of what the bicycle looks like, the brain needs to remember which neurons lit up. To do this, it strengthens the connections between them. This is a principle known as Hebbian learning – 'nerves that fire together, wire together'.

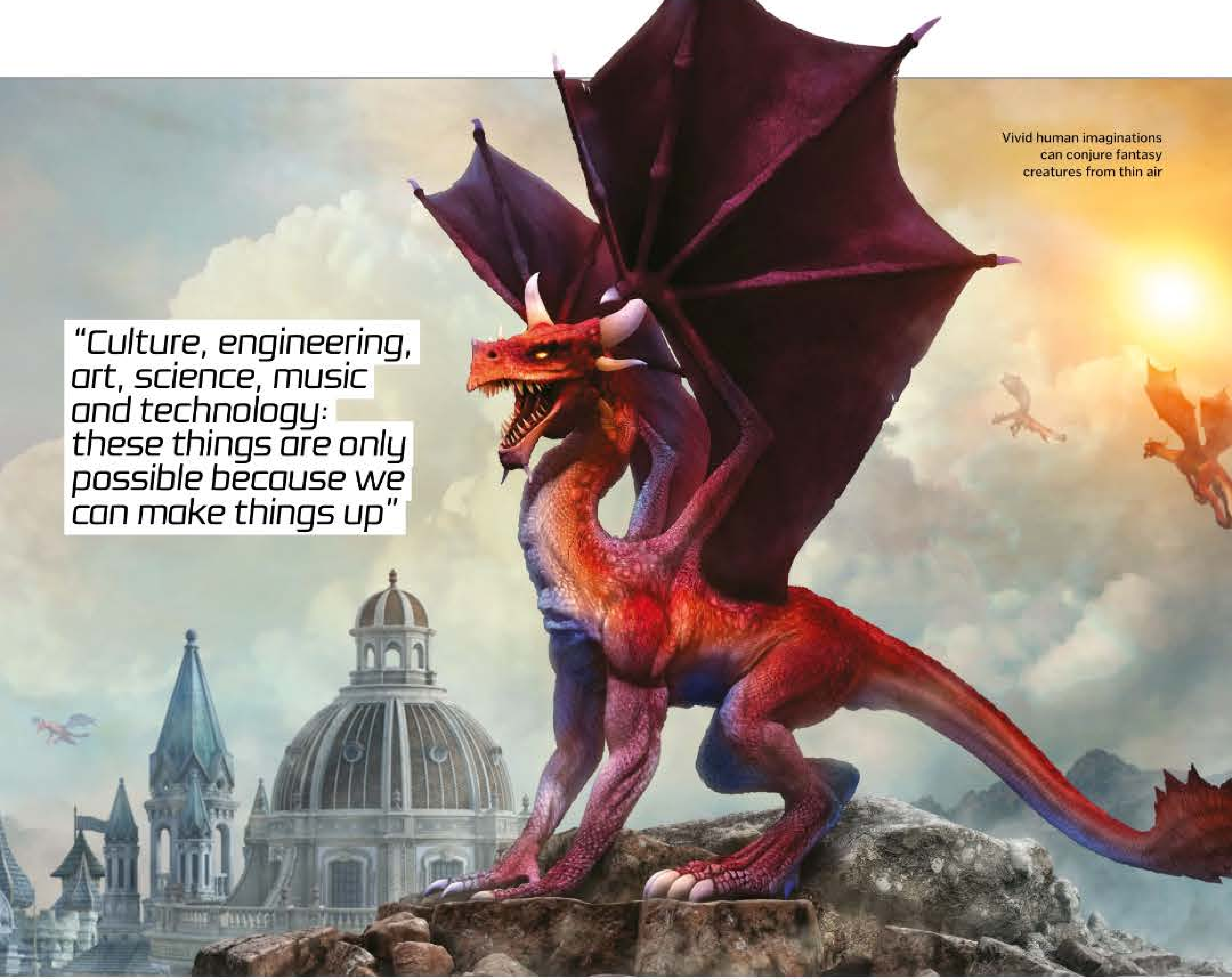
The result is that the brain forms a web of connected nerve cells that represent a bicycle, together known as a neuronal ensemble. To get the mental picture of the bicycle back, all the brain needs to do is reactivate the same connections. There's evidence that rats can do this to fill in the blanks when something's happening outside of their field of view; they use mental images to deal with missing information. But we can take it one step further.

Rather than simply recalling patterns we've already seen, we can use old patterns to invent something completely new. To do this, we borrow skills from the way we communicate.

Other animals also have language, but none quite like our own. Across most of the rest of the animal kingdom, language is non-syntactic. This means that animals talk about whole situations all at once. A bit like reactivating the whole mental image of the bicycle. The thing we can do differently is break situations down and talk about them in parts, known as 'syntactic language'. This makes room for us to reassemble the parts in a different order or take parts of different ideas and combine them together.

It's the combination of syntactic language and mental images that make imagination possible. Together they allow 'mental synthesis': the ability to break visual ideas apart and put them back together to conjure up objects that have never existed.

To imagine a dragon riding a bicycle, we need to connect the mental ensembles for the


Vivid human imaginations can conjure fantasy creatures from thin air

> "Culture, engineering, art, science, music and technology: these things are only possible because we can make things up"

different concepts and activate them together. For this to work, the signals from different parts of the brain have to arrive at the same time, and this takes some coordination.

The connections responsible are neural fibres that link the prefrontal cortex to the occipital lobes. Different neural fibres have different lengths, so for imagination to work, the brain needs to change the speed at which they pass their messages. This helps to ensure that the messages arrive together. The brain does this by wrapping the fibres in varying thicknesses of myelin insulation: the thicker the wrapping, the faster the fibres transmit.

Changes to nerve fibre insulation happen during childhood, when our brains are at their most plastic. When we're young, our brains also prune and refine the connections between different brain regions. This makes childhood a critical time for developing the skills of imagination, and it's something we practise a lot. While other young animals might fight,

Your brain has stored a pattern of nerve cell activity that means 'bicycle'

Practising imagining as children allows us to use this powerful brain skill as adults

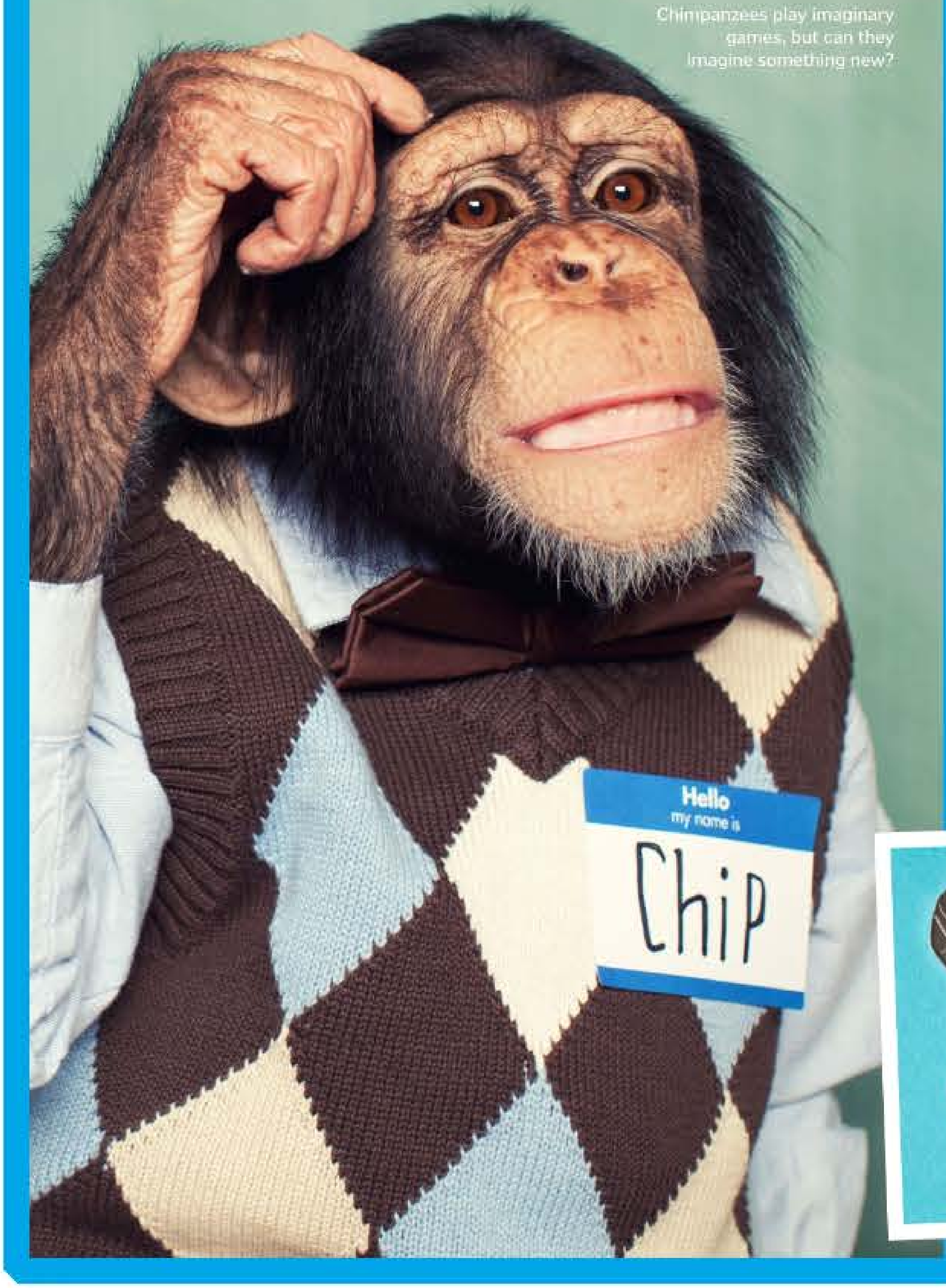
Can animals imagine?

Chimpanzees are our closest living relatives, but they don't seem to have the same powers of imagination as we do

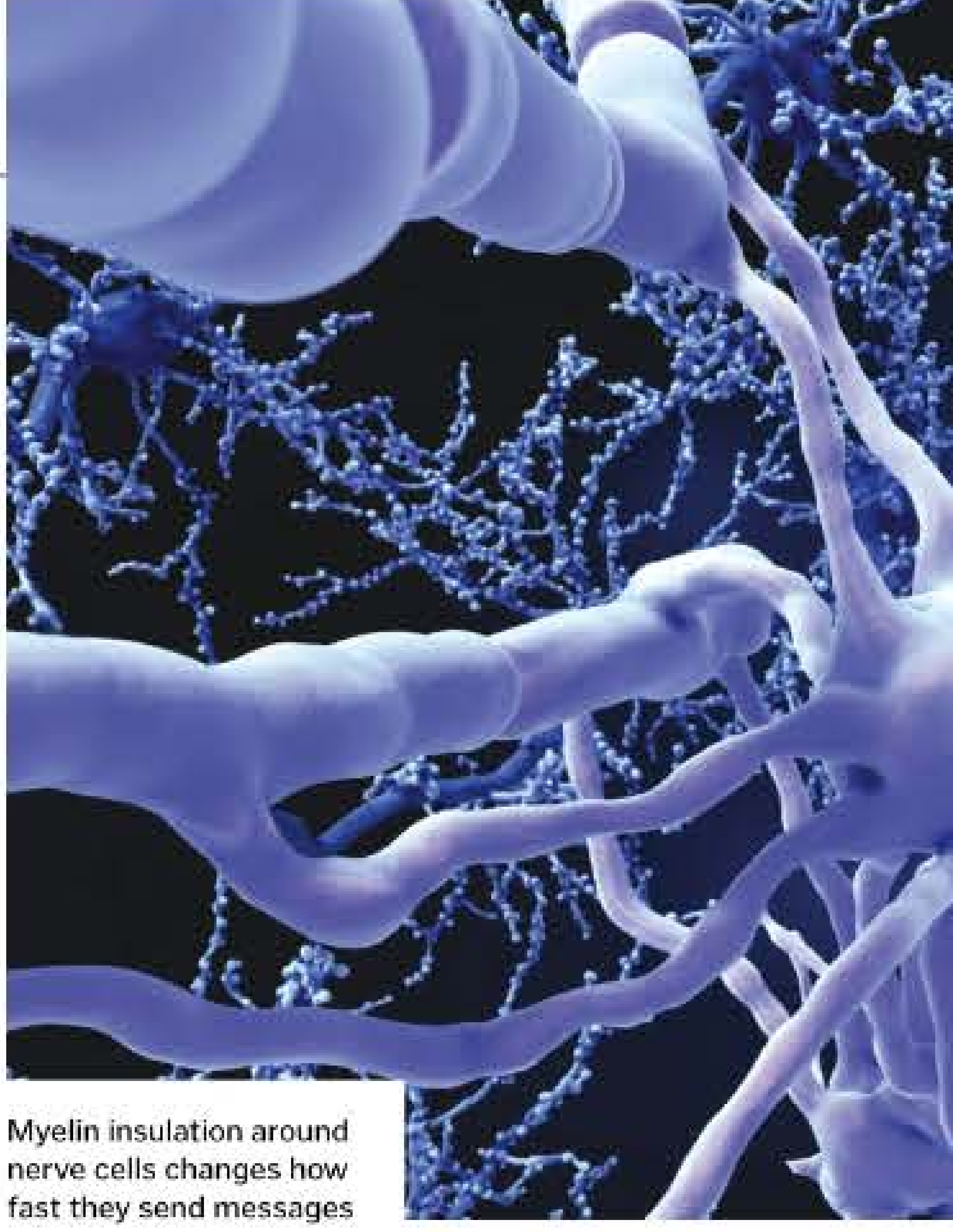
Animals can make mental images of things they've seen before. They seem to dream, with parts of their brains lighting up in the same patterns that they did during the day. They might even be able to conjure mental pictures of potential future events, allowing them to plan ahead. But the question is, can they do what we can do and mash different ideas together to invent something completely unexpected? Perhaps not.

The search for animal imagination has led scientists to our closest living relatives, chimpanzees, and, like human children, they do seem capable of imaginary play. In a famous example, a chimpanzee named Viki pretended to pull a toy on a string, even seeming to stop to free it when it became stuck on an imaginary obstacle. Another chimp, Kanzi, pretended to hide food in bushes and then pretended to eat it. He even shared his imaginary food with others and watched to see whether they would eat it too. But in both cases, the chimps were imagining behaviours that they had experienced before.

The thing that animals don't seem to be capable of, as far as we know, is to imagine completely new things. This skill seems to be unique to our species.



Chimpanzees play imaginary games, but can they imagine something new?



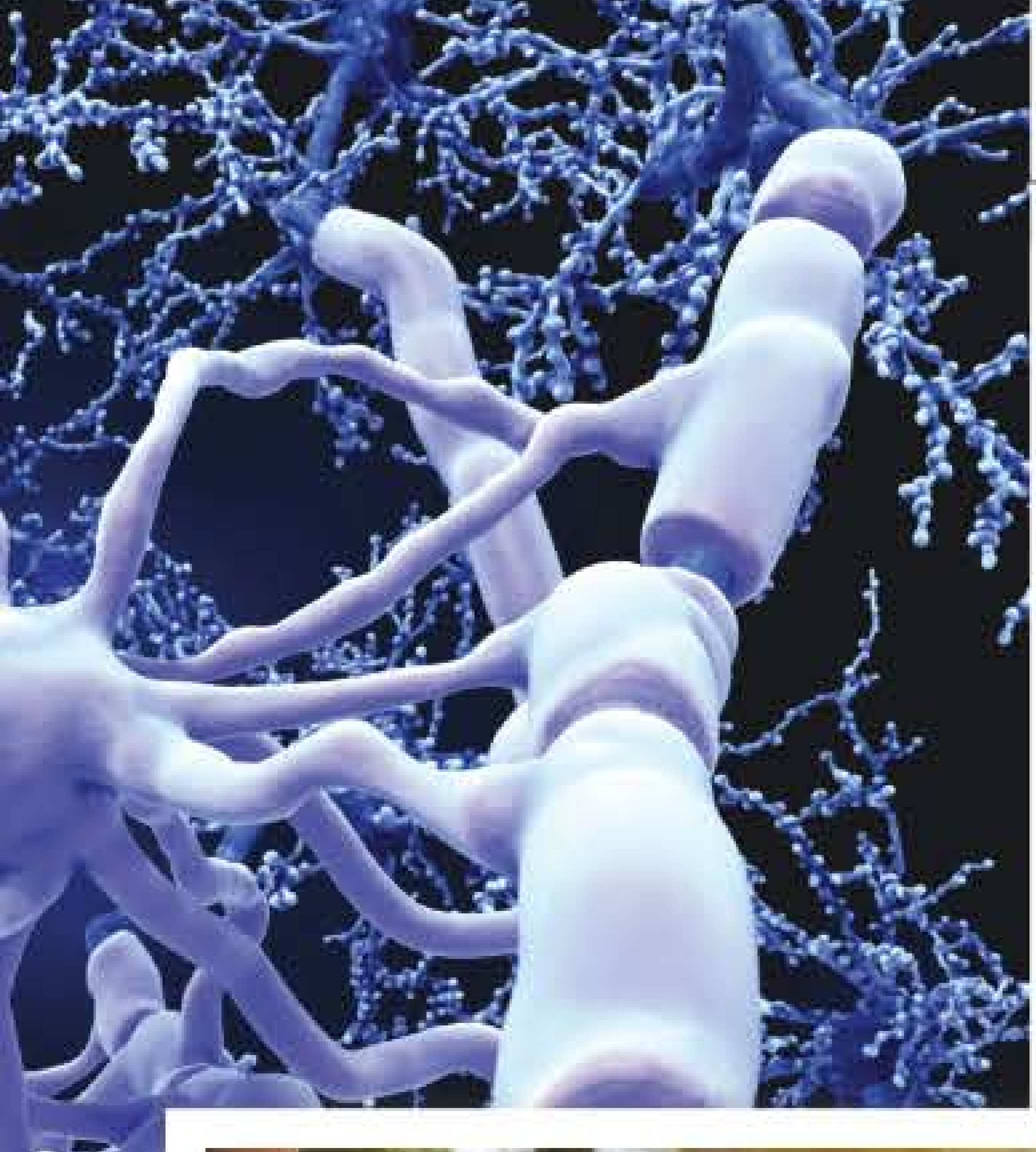
Myelin insulation around nerve cells changes how fast they send messages

climb and run to practise the skills they need as adults, our species are the only ones that seem to engage in make-believe. Imaginary friends are found nowhere else in the animal kingdom; we seem to have a unique gift for fiction.

The power of our imagination extends far beyond mental pictures of bicycle-riding dragons. Our brains contain 'mirror circuits' that activate not only when we do or experience something but when we see someone else do or experience the same thing too. For example, when we watch someone ride a bike, the centres in our brain that control movement light up. When we see someone fall off their bike, the parts of our brains involved in processing emotion switch on. These traces allow us to picture an experience in our mind's eye. And, like mental images, we can break them down and recombine them to imagine something new.

When children reach the age of around four or five, they also develop a complex imagination skill called theory of mind. This is the ability to understand that mental states – like knowledge, desires and emotions – can belong to us or belong to others. This lets us identify the goals of

Imagination enables humans to invent complex social contracts, like exchanging goods and services for money



Daydreaming allows the mind to find connections between different ideas

Imaginary friends might be uniquely human

those around us, understand their beliefs and understand that what people say and what they mean aren't necessarily the same.

The neuronal ensembles that we build have many complex and interlinking components. It's the ability to take all this stored information, break it into parts and put it back together that makes our imagination so powerful.

By the time we reach adulthood, we have a sophisticated ability to plan ahead. We can run through potential scenarios in our minds and attempt to solve problems before they arise. This lets us prepare in advance. We can compare more than one possible outcome, prepare for both, or weigh up which is more likely. We can imagine things that have never existed and that will never exist. And we can run simulations to find out what it feels like to experience things we've never experienced before.

To access these superpowers of imagination, we use two large networks of brain cells known as the 'executive attention network' and the 'default network'.

The executive attention network sits between the outer parts of the prefrontal cortex and the parietal lobe. It taps into your short-term memory and is especially active when you're focused on solving a problem. This part of your imagination is laser-focussed, but its creative powers have limits.

A task as simple as rotating a shape in your mind's eye involves at least 12 separate regions of the brain. Brain cells communicate across these different locations, creating what scientists call a 'mental workspace'. But to create the focus needed to solve difficult problems like this, the executive attention network does its best to cut out distractions from other areas. This helps to get the job done, but it doesn't allow room for random thoughts, and it's randomness that makes imagination so powerful.

To access your full creative capacity, you need to relax into the default network. This is the part of the brain that lights up whenever your mind starts to wander.

The main areas involved in the default network are the medial prefrontal cortex and the posterior cingulate cortex. Together, they handle memory, decision-making, reward and emotion.

When our attention is quiet and the brain enters a rest state, the default network takes control. The wandering mind is able to create and change mental images, recall episodic memories and relive thoughts and ideas, and by allowing many brain areas to be active all at once, it unleashes our unique human ability to integrate information.

One human imagination is powerful, but it's the combined imagination of the whole of humanity that has made our species such a success. It allows us to cooperate with other people on a scale much larger than any other organism on the planet, breaking down and recombining our shared experiences to reinvent the world around us.

Perhaps Albert Einstein put it best when he wrote, "Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution."

> *"We can imagine things that have never existed and that will never exist. And we can run simulations to find out what it feels like to experience things we've never experienced"*

Eyes have evolved from simple clusters of sensory cells to complex systems

HOW THE BRAIN SEES

Eyes are often likened to windows, but their role in our perception of the world is a little more complex

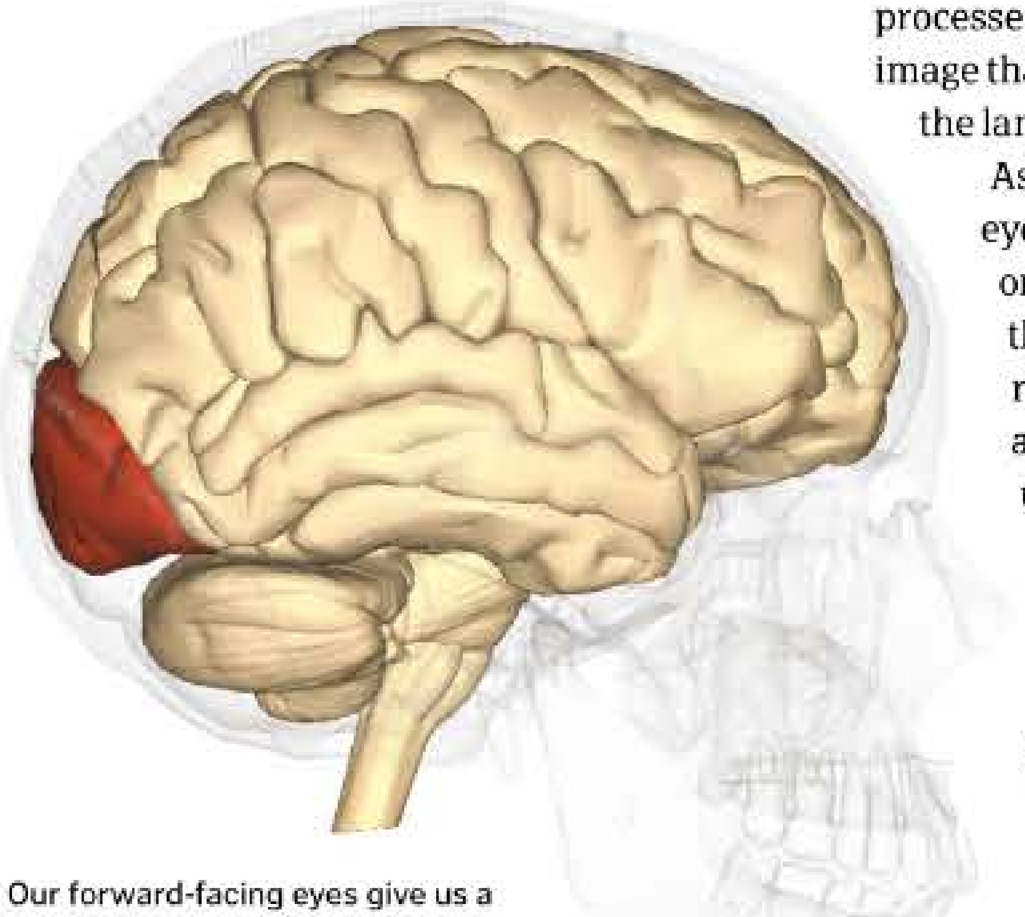
As light reflects off objects, waves enter the eye through the pupil. They're refracted by the lens and the cornea so that they reach the retina at the back of the eye. The retina is a sensory membrane made up of millions of light-sensitive nerve cells that fire electrical signals along the optic nerve to the brain when they're stimulated by light waves.

Because light travels in straight lines and enters the eye through a small, curved aperture, waves reflecting off objects above the eye hit the bottom of the retina and vice versa. This creates an inverted image of the world, but the brain processes these signals to produce a final image that matches the true orientation of the landscape.

As members of a predator species, our eyes are positioned quite close together on the front of our heads, meaning that the range of one eye overlaps with the range of the other so – unlike many prey animals – we can see directly in front of us. The brain combines the separate images to produce one seamless view.

This overlap in images, combined with information from features like shadows, allows us to perceive three-dimensional shapes, depth and distance with relative accuracy. It also means that we're often looking at our own noses from multiple angles, but this is something we rarely notice. As it's always there in the middle of your field of vision and isn't something you really need to be looking at, the brain ignores the nose and pieces together a clear view using the input from each eye.

Processing information requires energy, so the brain pays differing degrees of 'visual attention' in different situations. Sometimes it works quickly to gather a general impression of a person's surroundings and prevent them from falling or walking into anything. Only small, vital pieces of information are filtered through to conserve energy and prevent the brain being bombarded with useless signals. When something interesting catches your eye, however, it starts collecting more information and relating it to existing knowledge and memories for a more complete understanding of a particular scene.



Our forward-facing eyes give us a wider overlapping region than many prey animals

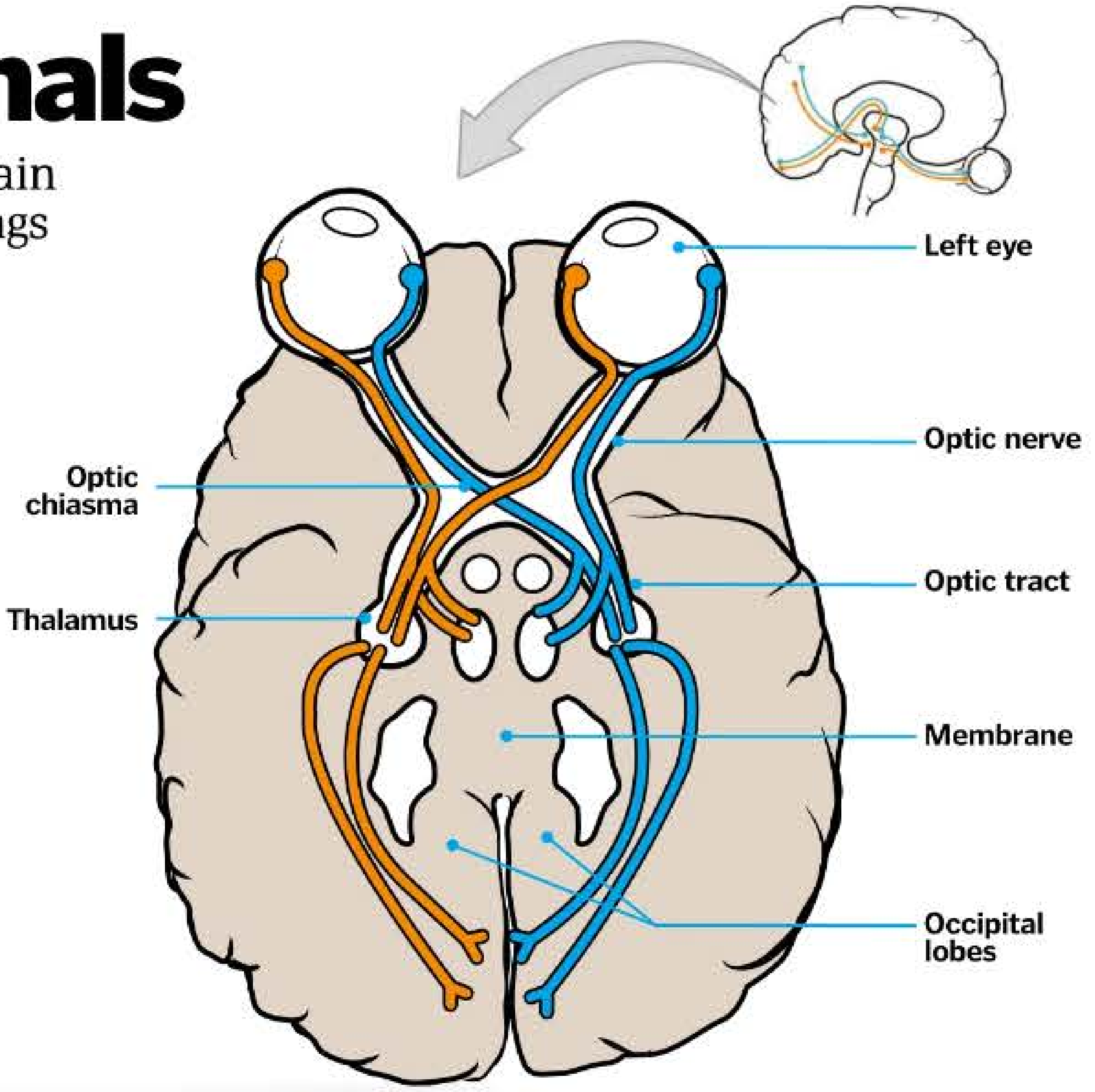
> *"Only small, vital pieces of information are filtered through to conserve energy"*

Sending signals

Working together, the eyes and brain build up images of our surroundings

No images are formed within the eyes themselves; they simply take in light waves and pass on information. When light waves hit the retina they activate certain cells, which fire electrical signals down the optic nerves. The optic nerves meet and cross at a point at the base of the hypothalamus known as the optic chiasm, so that each half of the brain can combine information from both eyes about one half of the visual field. Sorted into left and right, signals continue down the optic tracts until they terminate in the thalamus. From here they're relayed to the occipital lobe, which contains visual cortexes able to process, interpret and recognise visual signals.

Many neurons in the brain's visual region respond to contrast and edges. Edges and overall shapes are more useful than small details when the brain is initially building up information about an object. Once a shape is identified, other parts of the occipital lobe analyse features on the object's surfaces to gain more specific information. You can tell from a distance, for example, when a person is walking towards you, but it's not until they get closer and you can see their features that you're able to recognise who you're looking at.



In a busy environment, only a fraction of the information reaching the eyes is processed and stored by the brain

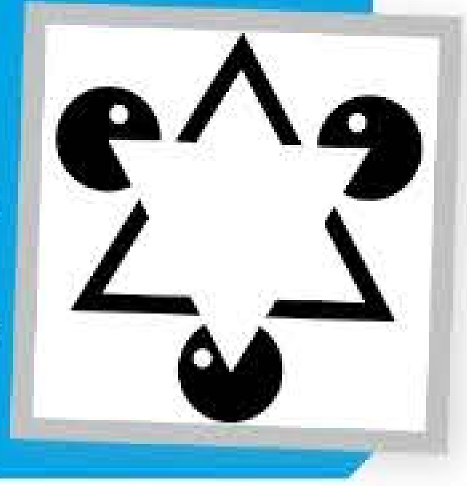
Fill in the blanks

The brain uses its immense power to allow us to see the unseen

The brain filters out a lot of visual information in order to conserve energy and enable us to focus on important objects and movements, but it also fills in the gaps to help us make sense of the world. A dog standing behind a picket fence is still recognisable as a whole dog rather than small segments of a dog, even though parts are hidden, for example.

This phenomenon, known as visual pattern completion, relies on the brain's ability to make connections and find patterns. When an apparently incomplete image is processed by the brain's visual region, it searches for a pattern to work out what's missing and delves into its stores of long-term memories. Using memories that match, it pieces together a satisfactorily likely image.

While visual pattern recognition is useful for understanding our surroundings, it can also make us 'see' things that aren't there. Features on an inanimate object can appear to make a face, while shapes in the shadows sometimes look just like human outlines until you turn and look at them directly. Cleverly drawn illusions rely on the brain's love of patterns, creating the idea of shapes where there aren't shapes and movement when the image is still.



Images: Anatomography; OpenStax

Never forget a face

We have facial recognition to thank for our wide social circles

Facial recognition helps humans to make and maintain strong social bonds

Humans are highly social animals, relying on others for comfort, safety and happiness. We live in large groups and often have additional connections outside of our close circles, and we're able to do this in part because we possess the ability to remember and identify faces. Faces of those who are important to us – whether for positive or negative reasons – are stored in our brains ready for the next time we encounter them. Even after years apart, old friends can recognise each other across the street, while the face of a stranger walking past fades from the memory almost instantly.

A part of the brain called the fusiform gyrus is often closely associated with face and body recognition. It forms part of the ventral temporal cortex, which is a series of structures involved in the processing of high-level vision and object recognition. A small part on the lateral side, known as the fusiform face area, appears to play multiple parts in recognition, including the ability to distinguish between objects that possess very similar features.

Facial recognition isn't an ability we're born with – poor eyesight and a brain that still has a lot of developing to do mean that babies can't learn and identify faces right away. Scientists debate when they begin to recognise familiar faces, with estimates ranging from two days to two months. Self-recognition is a more complex feat, with babies usually taking around 18 months to comprehend that they are looking at their own face in a mirror.

But not everyone is able to pick out a familiar face in a crowd. Some people suffer from prosopagnosia, or 'face blindness', a disorder that prevents them from remembering and recognising individual faces. Even the ability to recognise their own face in a mirror or photo is impaired. The disorder can arise as a result of brain damage, but in some people the ability to recognise faces never develops in the first place. No cure or effective therapy exists currently, so prosopagnosics often rely on other features like voice, gait and clothing to tell people apart.

Have I seen you somewhere before?

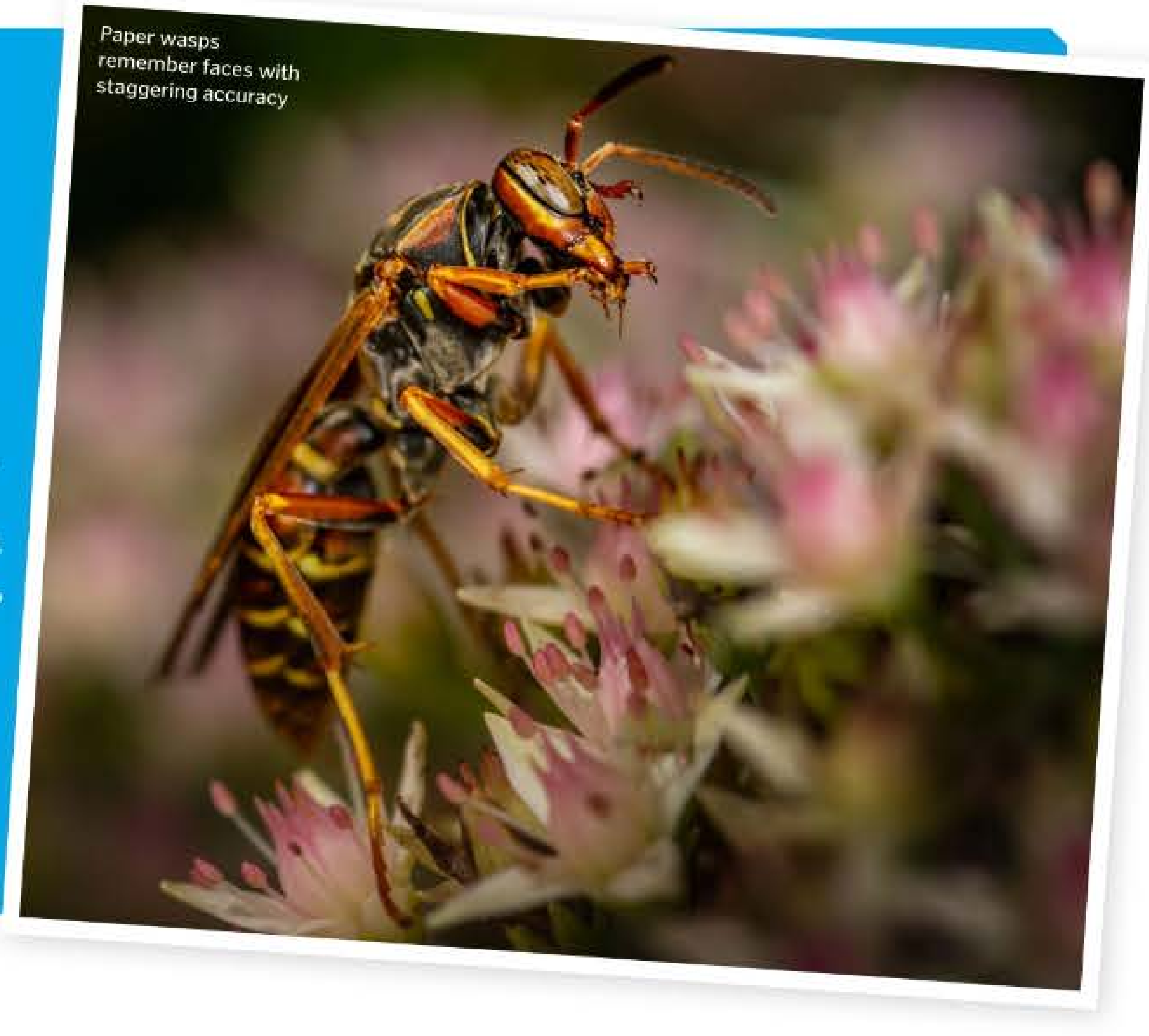
We're not the only ones who can pick out a familiar face

Many social animals can distinguish kin from strangers, and, like us, they use this ability to maintain bonds with family members and remember enemies. For creatures like paper wasps, facial recognition is a crucial tool used alongside other features like pheromones to quickly identify an intruder.

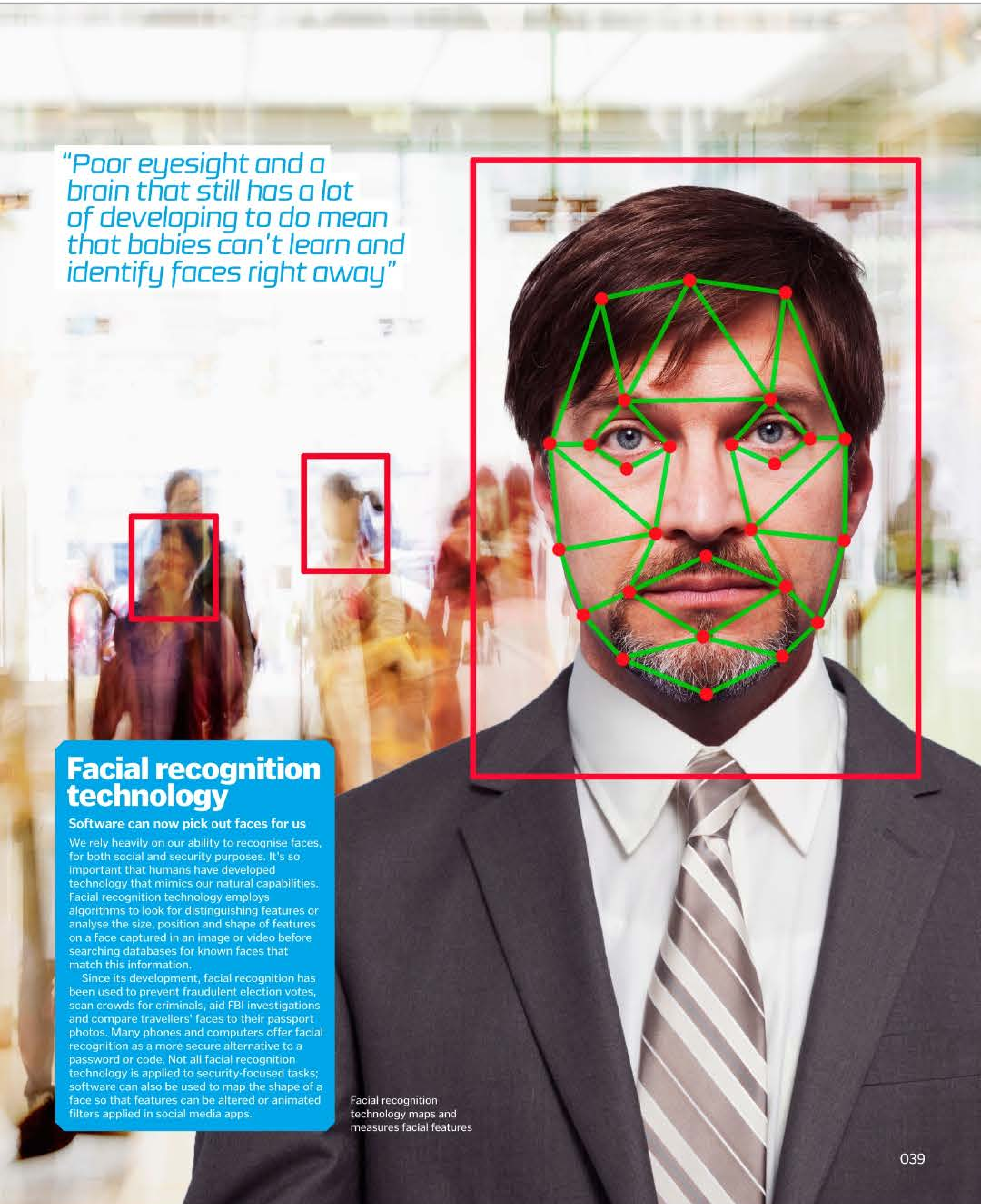
Dogs, descended from social wolves, can recognise each other and their owners, even identifying different emotions on human faces. Horses too can interpret how both their equine and human companions are feeling by looking at their expressions. Cats, on the other hand, don't seem to distinguish between human faces; instead, they rely on other cues like scent and voice tone.

Often thought of as possessing low intelligence, sheep were recently found to be able to recognise human faces. Shown a photograph of a person, they were able to pick it out when it was later displayed alongside another portrait. More impressively, they correctly selected the face of their handler without any training.

Recognising kin and even members of other species isn't uncommon in the animal kingdom, but self-recognition is a rarity. Aside from humans, only dolphins, great apes, orcas, magpies and elephants have shown that they understand who they're seeing when they look in a mirror.


Paper wasps remember faces with staggering accuracy

© Getty Images



"Poor eyesight and a brain that still has a lot of developing to do mean that babies can't learn and identify faces right away"

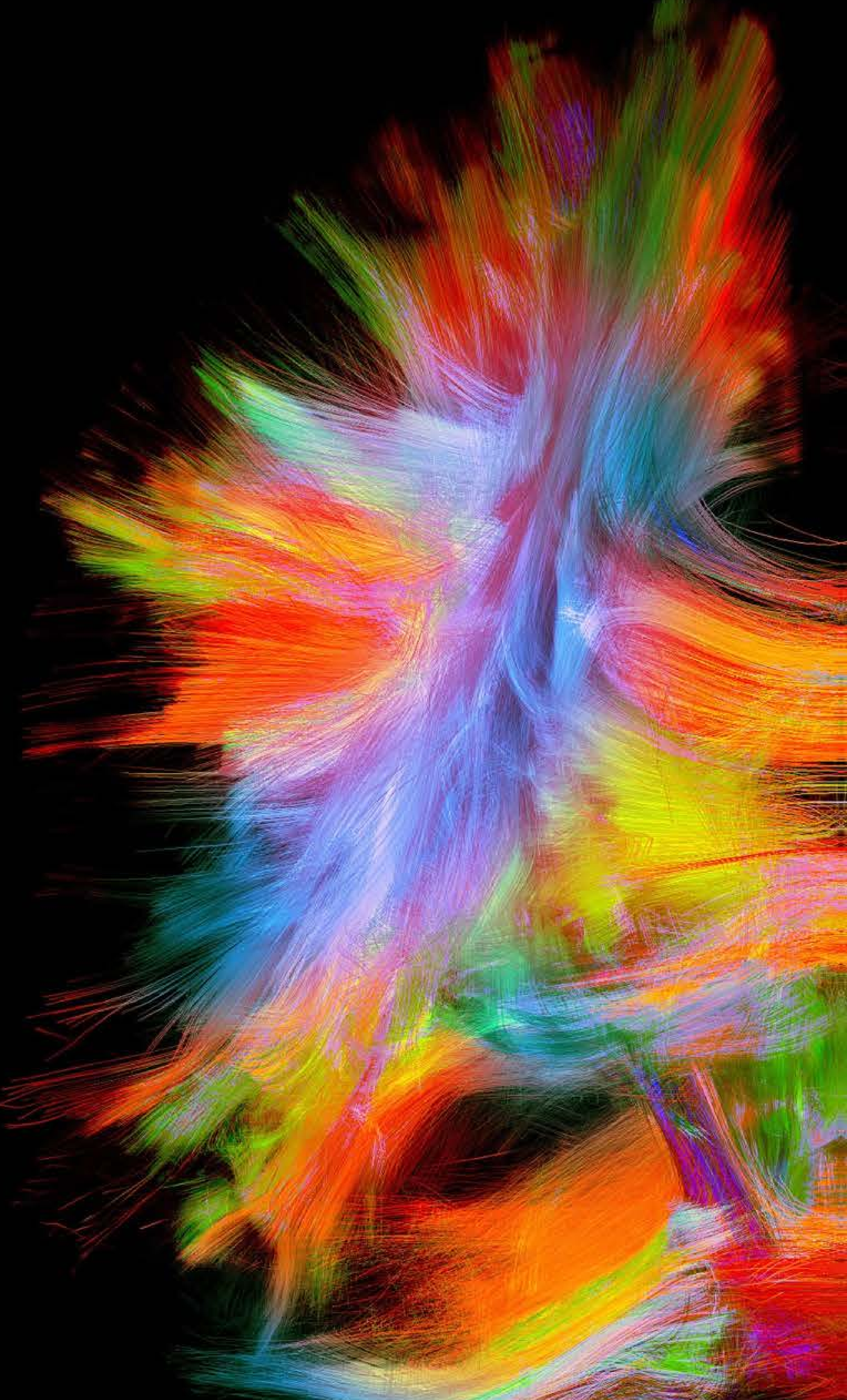
Facial recognition technology

Software can now pick out faces for us

We rely heavily on our ability to recognise faces, for both social and security purposes. It's so important that humans have developed technology that mimics our natural capabilities. Facial recognition technology employs algorithms to look for distinguishing features or analyse the size, position and shape of features on a face captured in an image or video before searching databases for known faces that match this information.

Since its development, facial recognition has been used to prevent fraudulent election votes, scan crowds for criminals, aid FBI investigations and compare travellers' faces to their passport photos. Many phones and computers offer facial recognition as a more secure alternative to a password or code. Not all facial recognition technology is applied to security-focused tasks; software can also be used to map the shape of a face so that features can be altered or animated filters applied in social media apps.

Facial recognition technology maps and measures facial features



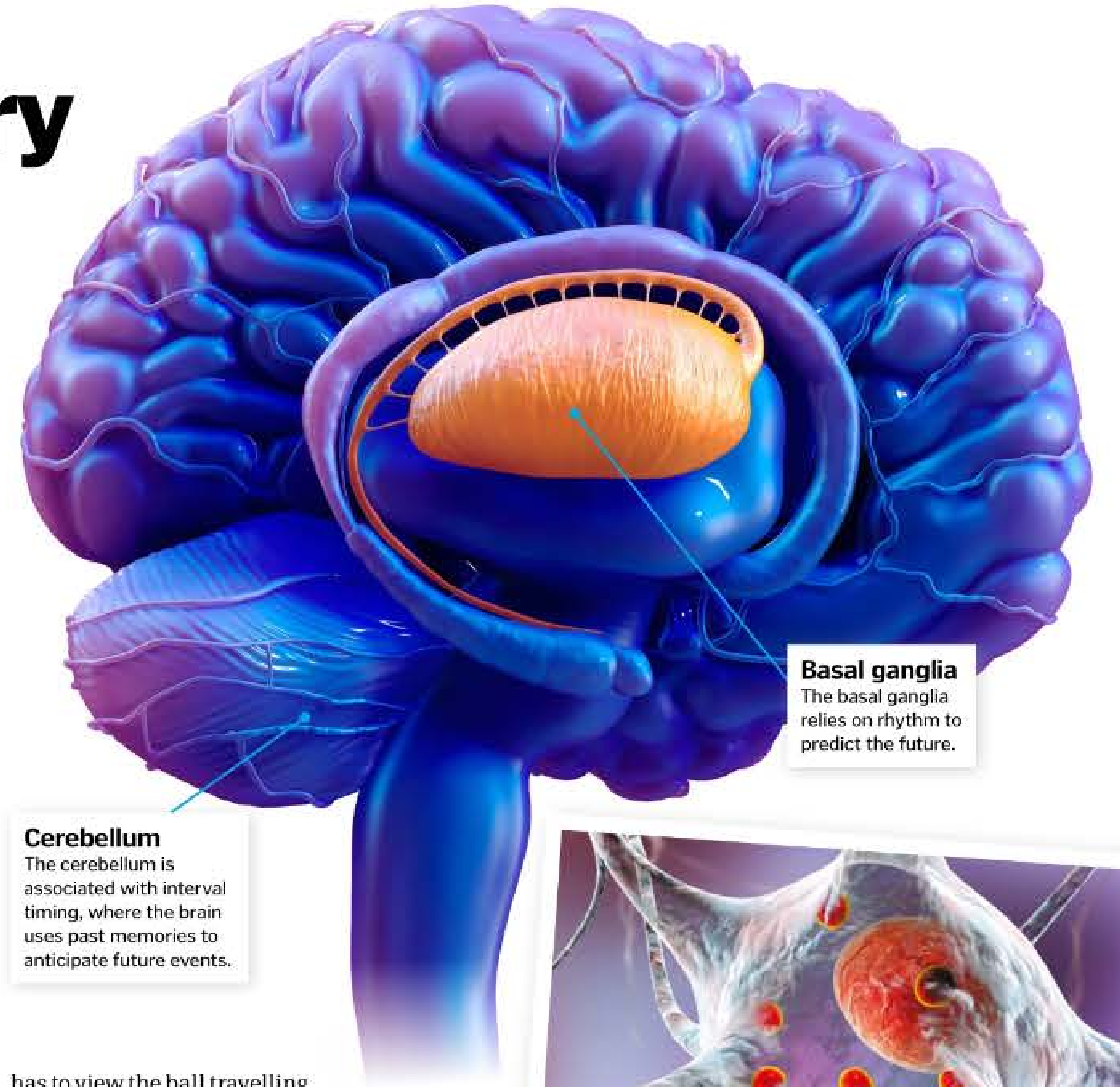
Technicolour mind

This stunning explosion of colour depicts the results of a full brain tracking.

© Getty Images

Anticipatory timing

The process that allows your brain to predict the future



Basal ganglia
The basal ganglia relies on rhythm to predict the future.

Cerebellum
The cerebellum is associated with interval timing, where the brain uses past memories to anticipate future events.

The brain is a powerful learning machine; it has the ability to learn from previous experiences in order to 'predict' future events. This is known as anticipatory timing and it is what enables humans to successfully navigate the world that we live in and also plays a key role in helping us to concentrate. But how does the brain do this?

Researchers think two different regions are responsible for its ability to 'predict' the future. These regions are known as the basal ganglia, a group of structures that are found deep within the cerebral hemisphere, and the cerebellum, which is located at the back of the brain. Both structures are associated with cognition and movement. The basal ganglia is associated with tasks that involve rhythm – such as singing along to your favourite song – while the cerebellum is connected to past memories – for example, being able to predict when a traffic light will change from red to green. The researchers also found that if one of these areas becomes damaged, the other region has the ability to compensate, and this is important in understanding neurodegenerative disorders such as Parkinson's disease. This research challenges previous theories that suggested a single brain system was responsible for all our timing needs.

Most notably, the ability to predict the future is essential for professional athletes – it takes longer to execute a swing than the time a batter has to view the ball travelling towards them.

Furthermore, researchers in another study found that the brain could predict events twice as fast as they actually occurred in real-time. This ability to predict the future could be the reason for the success – and survival – of our species, as we are able to predict the possible consequences of an action.

Parkinson's disease is caused by the loss of nerve cells in a structure of the basal ganglia called the substantia nigra

Built for sport

Not only are athletes' bodies finely tuned machines, but their minds are too

In the professional sporting world, the speed and precision with which athletes make decisions can be the difference between success and failure. But it's not just their bodies that are built for sport – it's their brains too. Studies suggest that some areas of athletes' brains are larger than those of their less-physically able counterparts.

Researchers at the Chinese Academy of Sciences compared the brains of professional divers with those who did not participate in professional training. The researchers found that three regions – the left superior temporal sulcus, the right orbitofrontal cortex and the right parahippocampal gyrus – of the professional divers' brains were significantly thicker than the non-athlete group.

Another study revealed that professional cricket players were more able to accurately predict the trajectory of the ball significantly earlier and with greater accuracy than the non-professional players – a skill that is vital for success in a match and one that has also been demonstrated in other ball sports, including basketball, football, tennis and hockey.

It is important for professional sports people like cricketers to be able to predict the future trajectory of the ball

Does our brain unconsciously control our decisions?

The science of making decisions

To do, or not to do?

We make hundreds of decisions every day; some are trivial, like deciding what to eat for breakfast, others are more complicated – and have consequences – such as deciding whether or not to apply for that job. Making a decision is one of the most essential human behaviours, but just how does the brain make a decision?

Decision-making is a complex process, and although it has been studied for years, it is a process that we only partially understand. What we do know is that there's not one single decision-making region of the brain but rather various brain regions – including the anterior cingulate cortex, orbitofrontal cortex (a region in the prefrontal cortex) and ventromedial prefrontal cortex – that work together to make a decision. Scientists think that the ability to stop or modify a decision is controlled by two individual locations within the prefrontal cortex and the frontal eye field that requires ultrafast communication between the two areas. It's also thought that emotions may play a role in the decision-making process.

It has long been suspected that injuries or damage to the anterior cingulate cortex or ventromedial prefrontal cortex can affect a person's ability to make decisions. In 1848, American railway worker Phineas Gage suffered a severe brain injury when a metre-long iron rod was impaled through his skull. Although Gage survived, he experienced major changes in his behaviour and personality, and since then it has been thought that the orbitofrontal cortex plays a significant role in decision-making.

In a 2004 study, researchers found that different areas of the brain are active depending on whether the participants were told to do something or were able to exercise autonomy. Another study found that the brain is less likely to be able to make important decisions later on in the day as a means of conserving energy.

Is free will just an illusion?

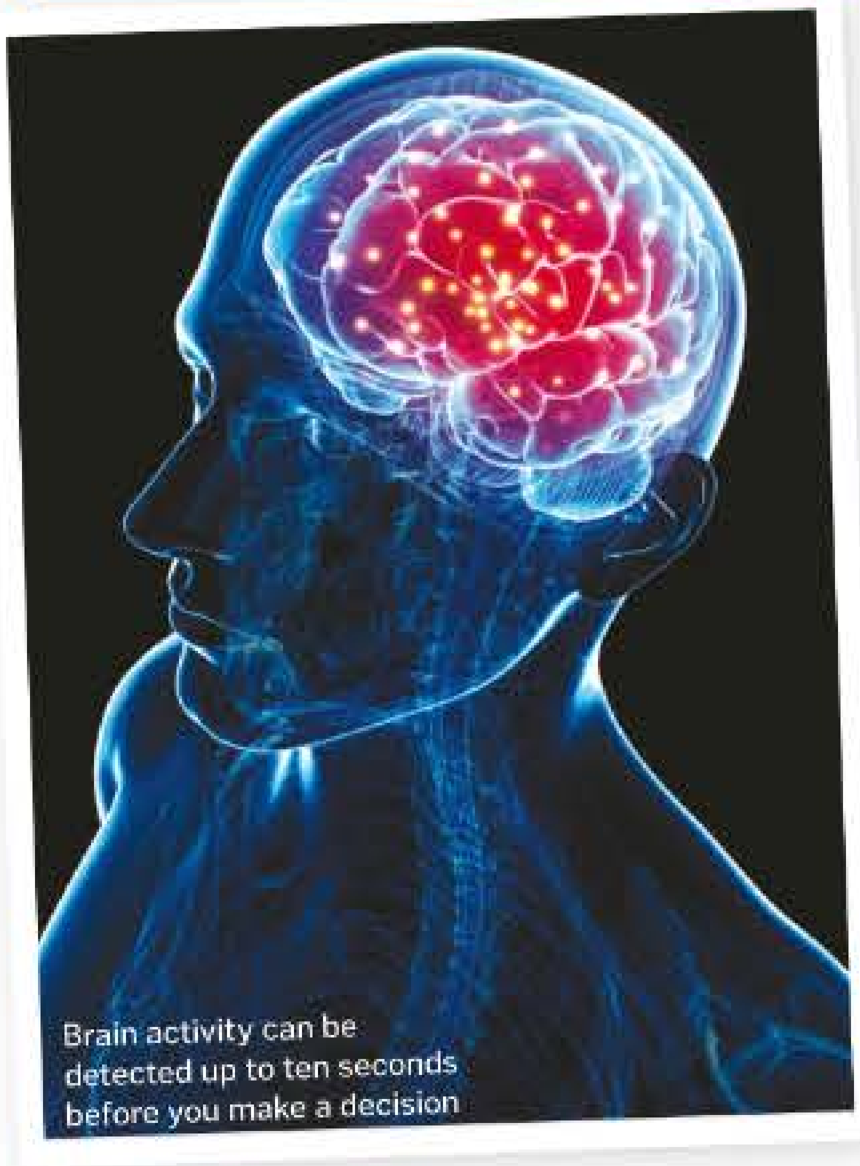
How the brain makes its mind up before you even realise

We believe that we must first have a thought to which we then respond. But in the 1980s the American scientist Benjamin Libet performed an experiment that suggested that the brain shows electrical activity before a conscious decision is made. The results of these experiment proved controversial, and the method was further developed by Professor John-Dylan Haynes from the Max Planck Institute for Human Cognitive and Brain Science in Leipzig, Germany.

Haynes' research team asked 14 volunteers to complete a decision-making task. The task was to press one of two buttons with either their right or left hand, but they had to remember when they made their decision. The researchers found that it was possible to predict the volunteers' decisions by monitoring brain activity in the frontopolar cortex up to seven seconds before – possibly ten seconds before due to the delay in imaging – they reported their decision. Other studies since have also produced similar results, all of which raises some very interesting questions about the concept of free will and whether we truly are in control of all the decisions that we make.

In 2002, two psychologists in the US tested the idea of free will being an illusion by placing two groups of volunteers into separate rooms and asking them to read two very different articles on the subject: one argued that free will is a myth while the other piece was neutral on the subject.

Once both groups had finished reading they were asked to take a maths test and incited to cheat. Tellingly, the group that had read about the falsehood of free will were far more likely to cheat. The results were the same when both groups were later encouraged to 'steal' in another part of the experiment. It seems that when people stop believing in free will, they stop seeing themselves as blameworthy. The potential consequences of society losing its faith in freedom of thought are clear to see.


Brain activity can be detected up to ten seconds before you make a decision

© Getty; Alamy

FIGHT OR FLIGHT

The brain's ancient threat-detection system gets us out of danger at lightning speed, but at what cost?

The fight or flight response is all-consuming. Your heart beats faster, your breathing becomes quick and deep, your palms sweat, and your mouth goes dry. With fractions of seconds to react in the face of danger, this is what gets you out of harm's way before you've even had time to think. It's an ancient self-defence mechanism that's hard-wired into the nervous system – your body's way of getting you ready for battle.

The body's panic button is a walnut-sized piece of brain tissue called the amygdala, and its job is to monitor incoming sensory signals for signs of threat. It is connected to a larger brain area called the thalamus, which acts as the brain's sensory relay. The thalamus gathers inputs from the brain's sensory processing areas and from the internal organs, and the amygdala listens in. When something doesn't look quite right, the amygdala has just seconds to get the body ready to fight or flee, and this involves synchronising all the organ systems to divert resources to the muscles. The fastest way to do this is to talk to the master controller of the body, the hypothalamus.

The hypothalamus sits in the middle of the brain, monitoring and adjusting everything from temperature and thirst to appetite and sleep cycles. It wires into the autonomic nervous system, which sends electrical impulses down through the spinal cord and out into the body. It also has a direct line to the pituitary gland, a long-range hormone signaller that pumps chemical messages into the blood.

The autonomic nervous system has two parts, which provide opposing sets of instructions to the organs. The sympathetic nervous system revs the body up, and the parasympathetic nervous system calms it down.

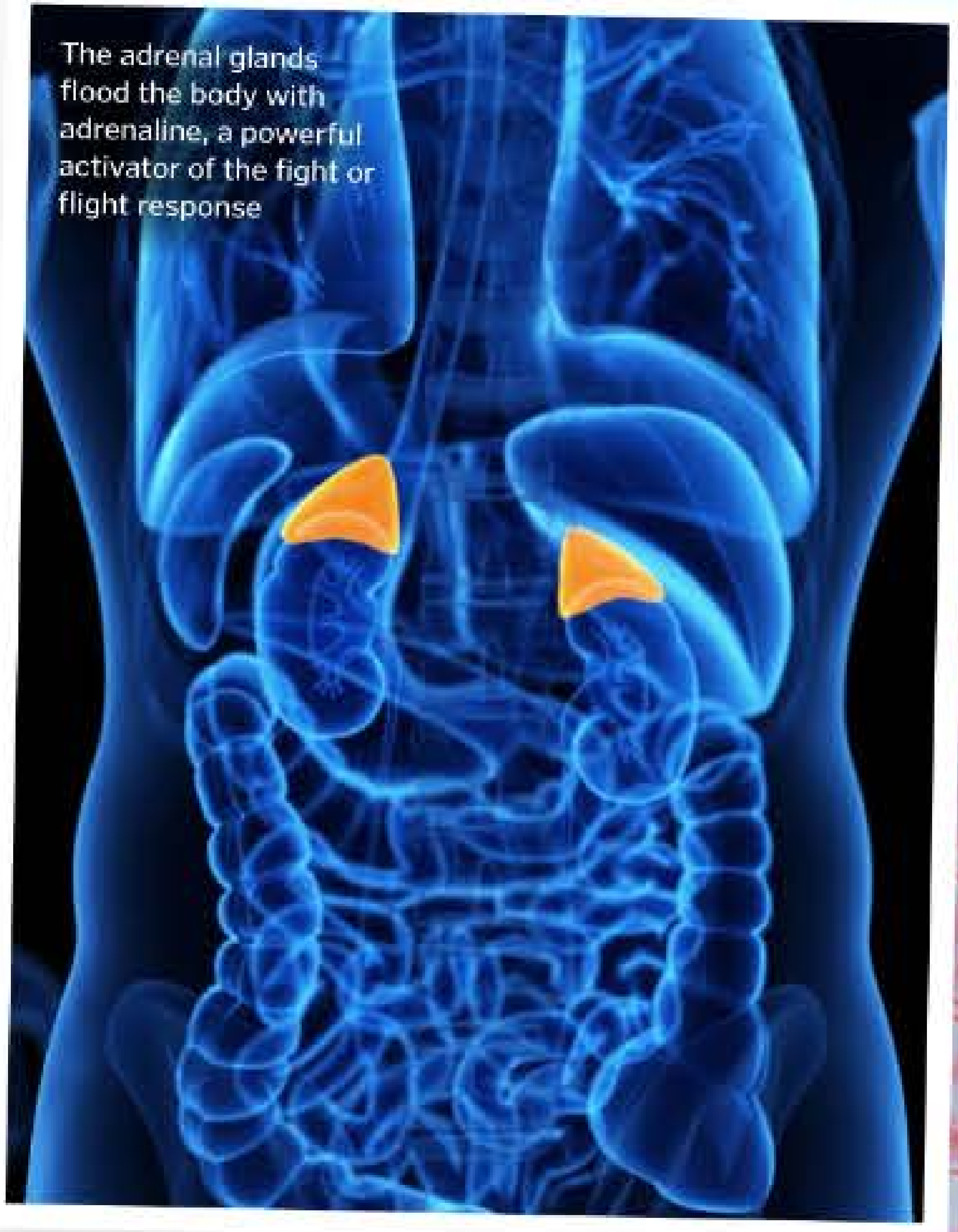
Nerve signals move faster than hormones, so the first part of fight or flight kicks this system into action. When the hypothalamus receives a danger signal from the amygdala, it switches the sympathetic nervous system on, which then sets off a cascade of electrical messages that result in the release of a neurotransmitter that's called noradrenaline. The muscles and organs are on constant alert for this signal – they have adrenergic receptors that can detect when noradrenaline is released from nearby nerves. When the signal finally arrives, the organs start to respond.

The heart beats faster and the blood vessels constrict, boosting blood supply to the muscles and brain. The airways relax, letting more oxygen pass into the bloodstream, and the liver releases glucose for extra fuel. The pupils widen to allow as much light in as possible, sharpening central vision, and the hands and feet become sweaty, improving grip. For a few moments you become superhuman. To allow all of this to happen, non-essential systems have to slow down. Blood vessels to the digestive system, skin and kidneys narrow, diverting vital nutrients away. Saliva dries up, appetite disappears and the stomach stops churning.

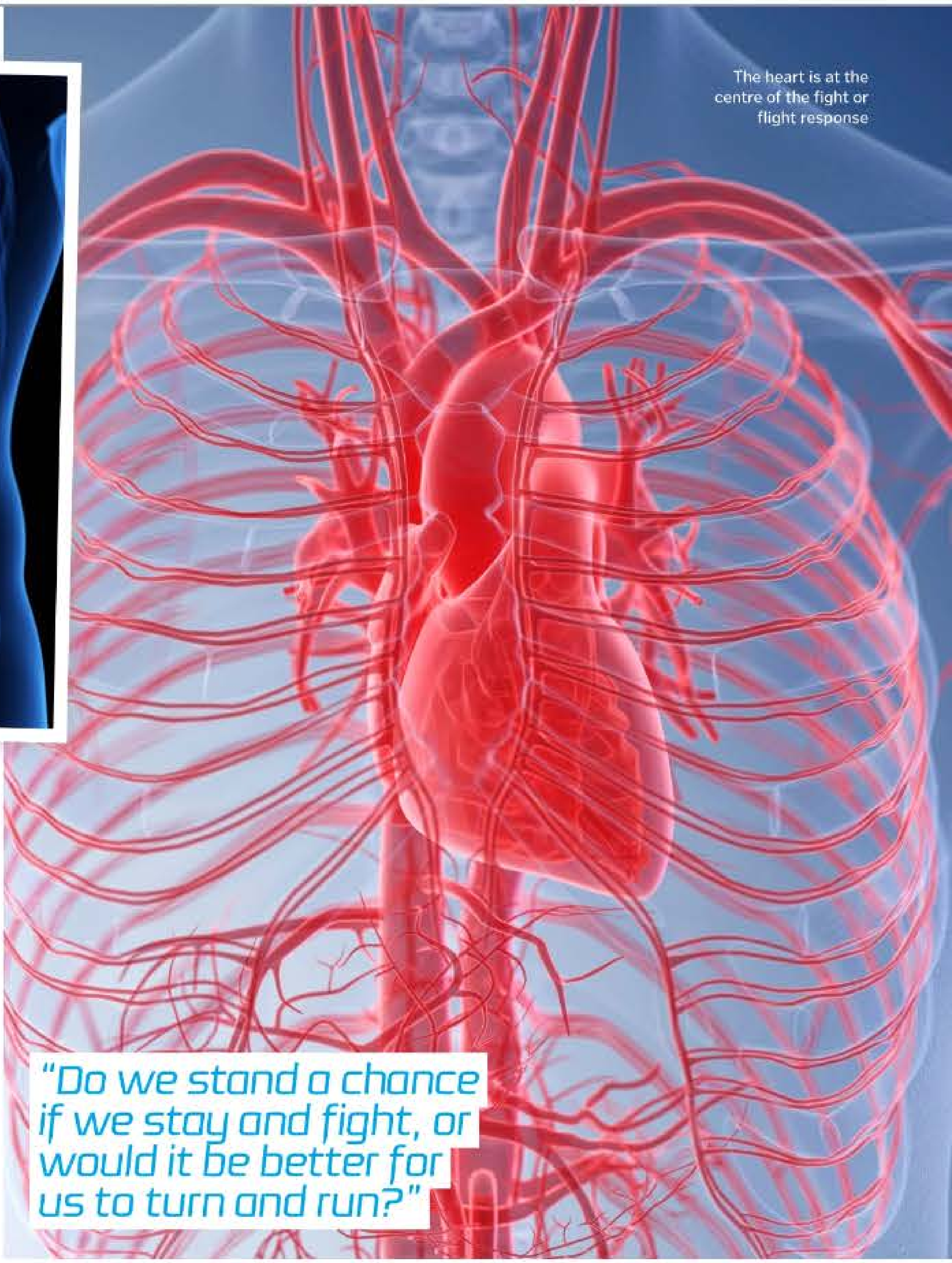
Noradrenaline is powerful, but the body has a second chemical message that takes the fight or flight response to the next level: adrenaline.

The fight or flight response evolved to help us cope with imminent danger

"The heart beats faster and the blood vessels constrict, boosting blood supply to the muscles and brain"



The adrenal glands flood the body with adrenaline, a powerful activator of the fight or flight response



The heart is at the centre of the fight or flight response

> "Do we stand a chance if we stay and fight, or would it be better for us to turn and run?"

The sympathetic nervous system sends danger signals to the adrenal glands. Positioned just above the kidneys, these small organs are hormone factories, and their job is to flood the blood with adrenaline. Deep in the centre of each one, in a part of the gland called the adrenal medulla, chromaffin cells start adrenaline production. These cells connect to their neighbours via tiny holes called gap junctions, so when one receives a danger signal, the others respond as well.

The adrenal glands get some of the best blood supply in the body, helping to get the adrenaline out into the system at lightning speed. Messages pass through so fast that by the time adrenaline production starts, the brain's cortex might not even have clocked the threat.

When we need to get out of the way of a speeding car, we don't have time for conscious thought. It takes about two minutes for full adrenaline production to switch on, and by this time the cortex has caught up. Conscious processing comes back on line and the powerful, problem-solving parts of the brain can help with decisions about what to do next.

Do we stand a chance if we stay and fight, or would it be better for us to turn and run? Whichever conscious choice we make, the fight or flight response has already made sure that the body is ready.

Sometimes, the answer is neither fight nor flight, and the body's built-in defence system has a solution for that too. If a predator is nearby but hasn't seen you yet, it can be better to freeze to avoid detection. The prefrontal cortex and the anterior cingulate cortex talk back to the amygdala and hypothalamus. They can override the sympathetic nervous system with parasympathetic signals, slowing the heart rate and calming the body down in the hope that the danger will pass.

There's only so long that the body can maintain a full-blown fight or flight response. We can't divert blood away from the digestive system all day, so there's a second phase of the response that kicks in later if the danger still hasn't subsided. This is the stress response.

Stress signals come through the same pathway, beginning in the hypothalamus and ending in the adrenal glands, but they travel by a different route. This time, the hypothalamus talks to the pituitary gland, telling it to release the adrenocorticotropic, or ATCH, hormone, into the blood. This then travels to the outer part of the adrenal glands, the adrenal cortex, which then switches on production of the stress hormone, cortisol.

Cortisol backs up the fight or flight responses for more long-term survival by changing the body's metabolism. It releases sugar into the blood for fuel and dampens non-essential systems like reproduction, the immune response, growth and digestion.

The fight or flight response has helped our species to flourish in the face of some of the most dangerous situations on the planet, but it's not unique to humans. The ability to adapt to dangers in the environment, or to escape if adaptation isn't possible, is a fundamental part of animal survival.

Some fight or fight responses are incredibly simple. Bacteria, for example, can sense danger in their environment and respond by switching genes on and off (fight) or moving away (flight). But, as organisms get larger, the responses become more complex.

A fight or flight system for a complex body like ours depends on a nervous system. We need to be able to speed the heart up or slow it down on demand to give our muscles the boost they need when we're in danger. Invertebrates can do this to some extent, but for the full experience it seems you need a backbone.

Lampreys are some of the most ancient living vertebrates, closely related to the ancestors that gave rise to all modern fish, amphibians, reptiles, birds and mammals. Their nervous systems are simpler than ours, but they still have the components that are needed to build the fight or flight response.

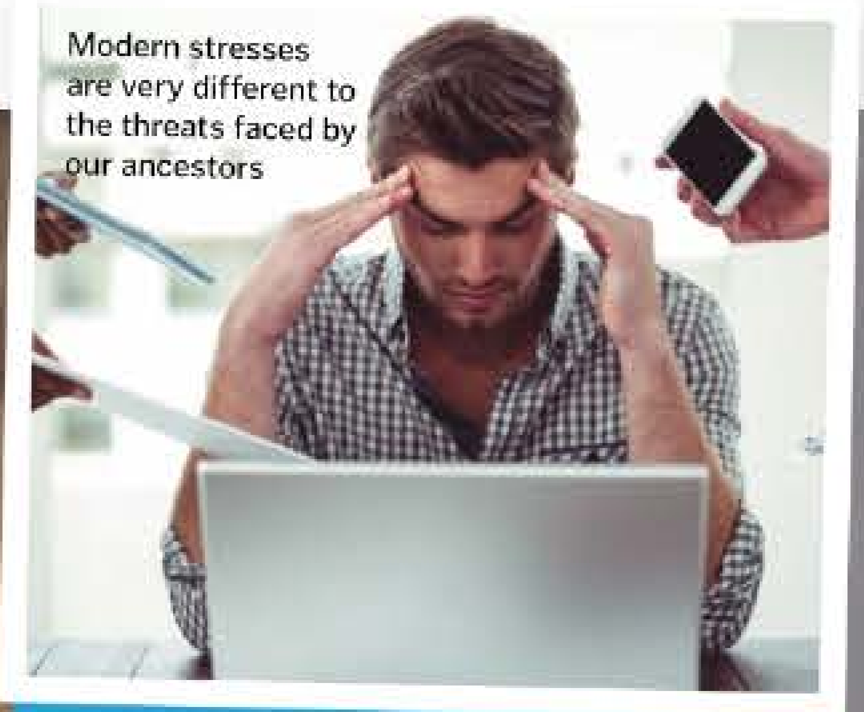
A look at the evolutionary tree reveals that simpler vertebrates rely more on adrenaline for their fight or flight responses, and as vertebrates became more complex changes to the nervous system gave their brains finer control. The sympathetic and parasympathetic nervous systems started to work as a pair to control heart rate and divert blood away from the gut, and we all use cortisol to manage stress.

Although the fight or flight response seems to be ancient, there are some unique things about the way in which humans react to danger. We are one of only two species in the entire animal kingdom that engages in war – bands of humans, and bands of chimpanzees, come together to kill other members of their own species in large-scale conflicts. It seems that this might have something to do with how our specific fight or flight systems evolved.

When researchers looked at one of the fight or flight genes in our brains, they found something different. There's a protein called Adrenoceptor Alpha 2C (ADRA2C), which sits inside the cortex of the brain listening for fight or flight signals. In lab experiments, mice born without the gene startle more easily and are quicker to attack, revealing that its normal job is to dampen the fight or flight response.

A look at the gene in humans and chimpanzees showed up a natural change in ADRA2C that means our brains make less of it. If we're anything like mice, there's a chance that this change might make us more volatile in response to fight or flight signals.

However, our fight or flight response seems to come at a cost. It might have originally evolved to get us out of danger, but it can just as easily get us into danger too.


Modern stresses are very different to the threats faced by our ancestors

Too much of a good thing

What happens if the fight or flight system won't turn off?

The fight or flight response evolved to get us out of sticky situations fast. But it's only supposed to work on short timescales. To boost muscle power in a time of crisis, the body has to borrow resources from other areas; when the crisis is over, those areas need their blood supply back. But what happens when the threat doesn't go away?

The fight or flight response gives way to the stress response. The sympathetic nervous system calms down and adrenaline production stops, allowing heart rate and blood flow to return to normal. In its place, cortisol kicks in. Known as the stress hormone, cortisol can talk to almost every cell in the body. Its main job is to change metabolism and dampen lower-priority activities like growth, reproduction and immunity. It does this by altering the release of reproductive hormones, interfering with molecules used to fight infection and changing the way that cells respond to growth factors. This helps to make sure that there's energy available to deal with the stressful situation, but it can cause side-effects, changing digestion, sleep patterns and mental health. Only when the stress subsides will the body return to normal.

The pupils constrict, sharpening central vision and blurring everything in the periphery

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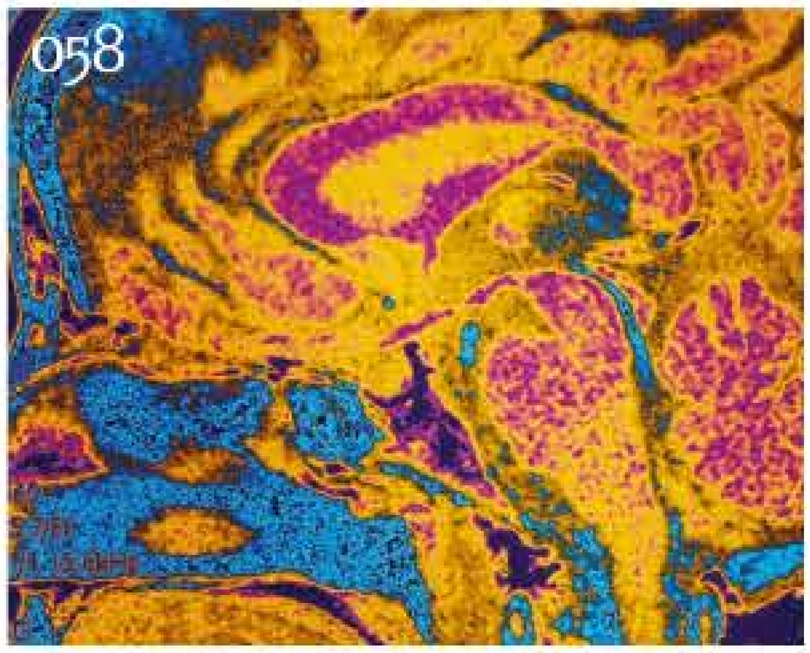

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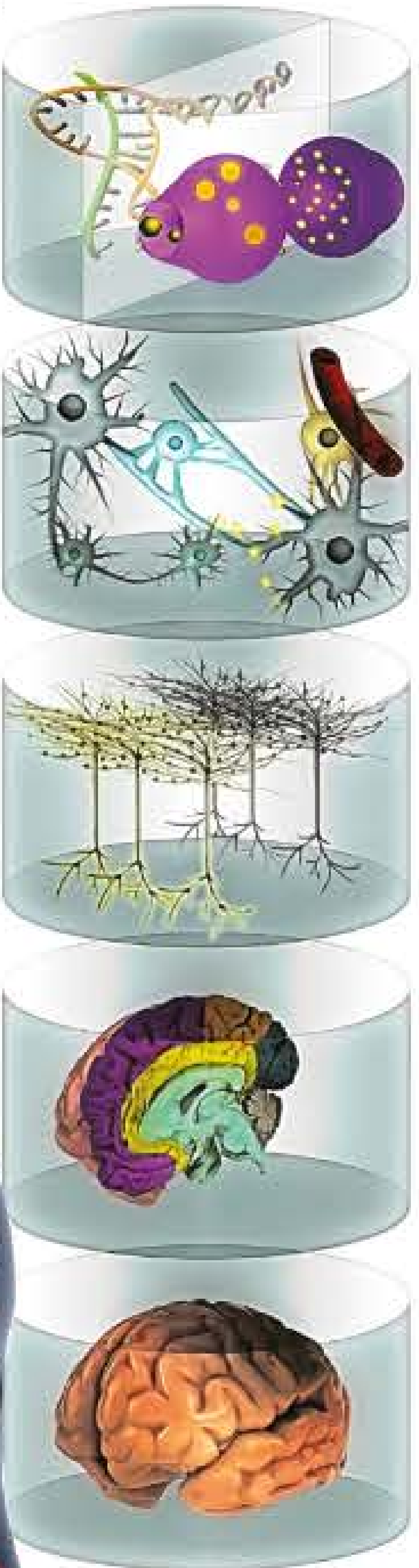

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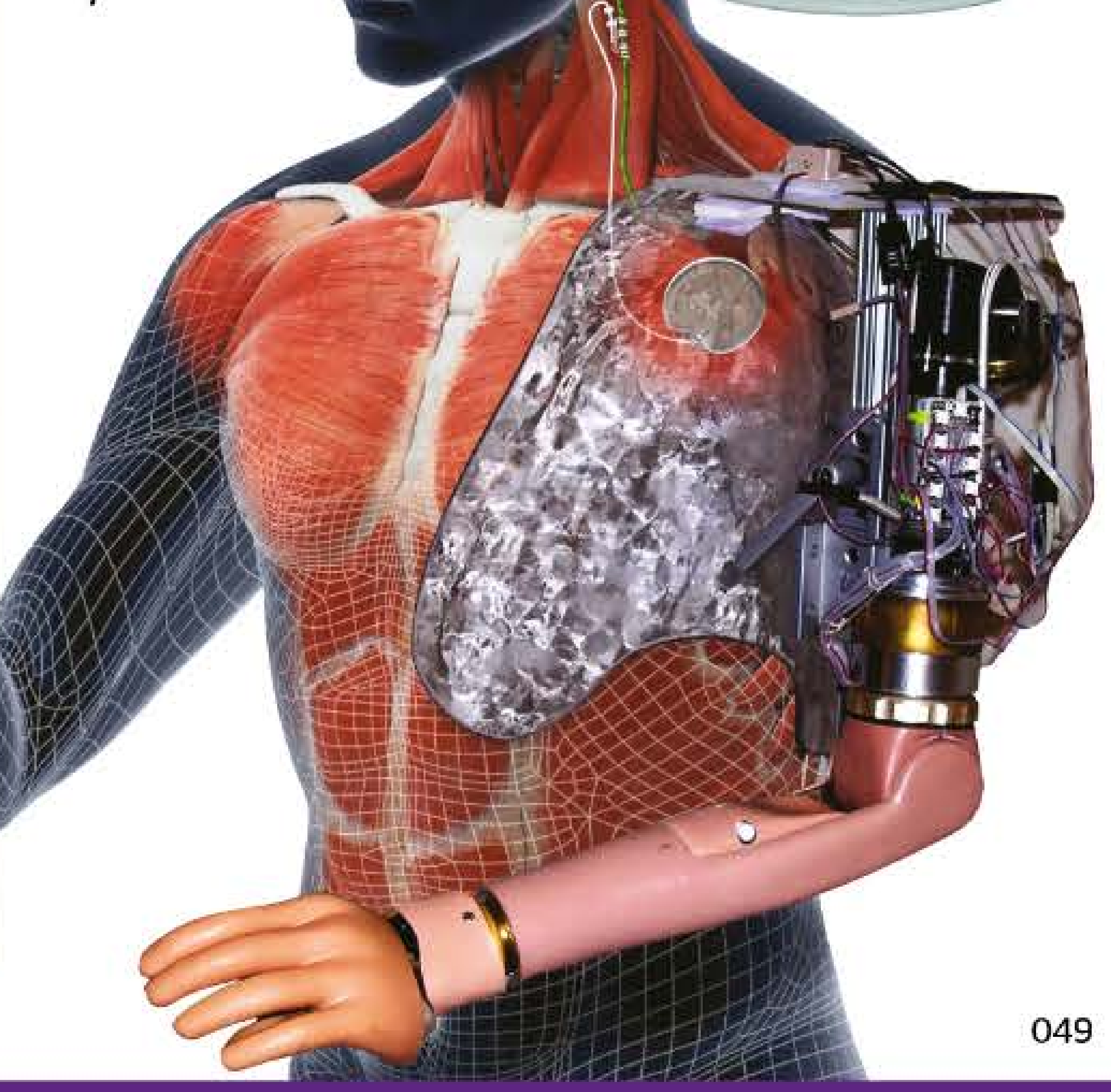


WHAT IS CONSCIOUSNESS?

Words by **Josie Clarkson**

To consider this question, you must be conscious – it's an *Inception*-level concept that has preoccupied scientists and philosophers for millennia

To demonstrate just how complex a subject consciousness is, let's explore the vast range of definitions provided by authority figures. The *Oxford English Dictionary* gives not one but three definitions of consciousness: 'The state of being aware of and responsive to one's surroundings', 'a person's awareness or perception of something', and 'the fact of awareness by the mind of itself and the world'. The English philosopher John Locke said, "Consciousness is the perception of what passes in a man's own mind." Dr Giulio Tononi, a neuroscientist, psychiatrist, and leading authority on the brain during sleep, defines consciousness as that which "corresponds to the capacity of a system to integrate information". The famous philosopher Descartes stated, "I think therefore I am." And the psychologist and philosopher William Davidson needed six pages to define it in his article *Definition of consciousness*, published in the journal *Mind*.

The variety of these definitions begs the question of what would even suffice as an explanation of consciousness. This needs to be outlined before the question 'what is consciousness?' can be answered.

Philosophers' thoughts

Many great thinkers have mused on the mysteries of the mind

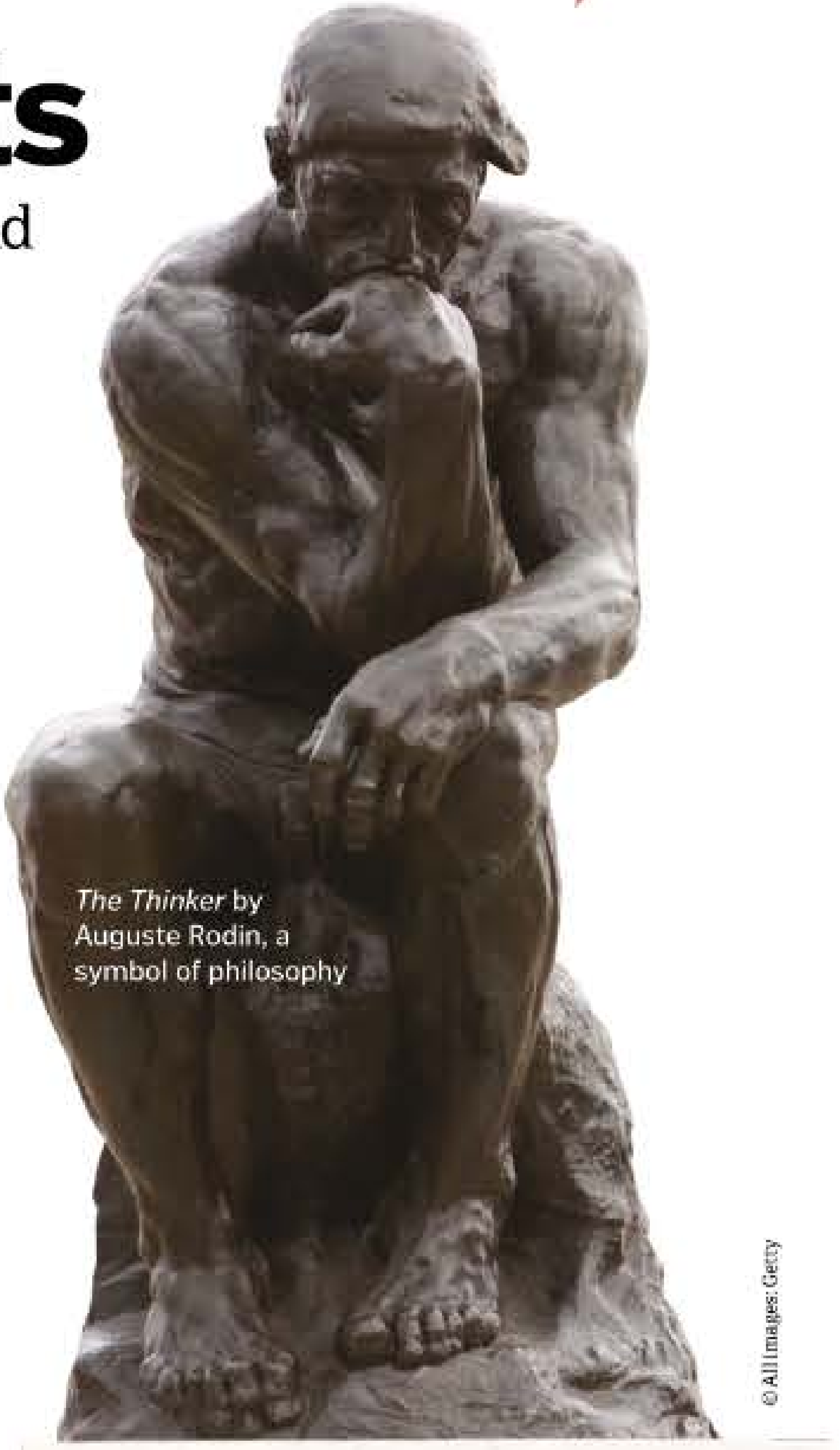
To highlight the complexity of consciousness, Australian philosopher David Chalmers uses the idea of 'easy' and 'hard', dividing consciousness into the parts that are less or more challenging to understand and study. An example of easy consciousness is whether a person is awake or asleep, because it can be objectively measured. Hard consciousness includes things like the awareness of subjective experience.

Philosophers have developed many theories, but there are two main ways of viewing consciousness. The first is called dualism, which describes consciousness as an abstract phenomenon that is not physical. The opposing theory is that consciousness is a physical process based on the activity of the brain and is known as materialism or physicalism.

Particularly mind-boggling ideas brought to us by philosophy include higher-order theories. These attempt to explain how thoughts move from the unconscious to the conscious mind. The 'order' part refers to a chain of thoughts about each other. For example, a person can feel hungry – this is known as a mental state – and that is accompanied by the thought of feeling hungry. When the thought makes the person aware of that mental state, it becomes conscious. The idea is that hunger is an unconscious feeling until there is a 'higher-order' thought about it. So there is a chain, or order, of thoughts throughout the brain all relating to one another that brings them into consciousness. A criticism of higher-order theories is that they are cyclical; they go on forever because there is always a higher thought in the chain.

Another theory is that human consciousness exists on three levels. The bottom level (C0) contains unconscious processing such as deciphering emotion from the facial expressions of others. One level up (C1) is the coming together and evaluation of information to produce a chosen response. The top level (C2) is where we find self-awareness and the ability to evaluate our own thoughts and actions.

Philosophers don't have the means to prove their ideas. This is where science comes in, testing philosophers' theories by trying to objectively measure consciousness.



The Thinker by Auguste Rodin, a symbol of philosophy

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"The Oxford English Dictionary gives not one but three different definitions of consciousness"

Thinking about the brain is known as metacognition

Scientists' thoughts

How research is revealing the secrets of sentience

Scientists can learn more about how the brain works by analysing scans

Scientists aim to measure consciousness using specialist equipment like brain scanners. These record a person's brain activity while they are thinking about different things or receiving different stimuli. Scientists can then analyse this activity to look for patterns that can explain certain behaviours.

Most neuroscientists agree that consciousness involves combining information from different parts of the brain. There is growing evidence to suggest that an area called the claustrum is where this information is combined. Neurons in the claustrum connect to most other brain areas, especially the cortex. The cortex is the outer part of the mammalian brain and is responsible for lots of tasks, such as receiving and interpreting sensory information (i.e. sound and vision). The claustrum could link all these processing areas and combine their products to produce a single conscious thought in the brain. The strongest connections (those containing the most neurons) are seen between the claustrum and the visual cortex, suggesting it could make a person aware of their surroundings.

In 2017, a team led by neuroscientist Christof Koch found three very large neurons wrapping around the brains of mice. The neurons started in the claustrum and had long, thin branches extending deep throughout the brain. This is physical evidence of information from across the whole brain merging into just three neurons.

It is important to remember that this evidence is just observational. Although these connections have been found, scientists have so far had to predict their function. To prove this hypothesis, scientists must demonstrate that something directly causes something else. This has not yet been done for the claustrum, so its true function remains unknown.

The main way scientists demonstrate the function of brain areas is to look at what happens when that area is missing. This could be because it has been damaged through injury or illness, removed surgically, or simply because a person was born without it. For example, removing the visual department in the brain leaves the individual blind despite their eyes remaining intact. To show this, only one brain area must be missing, otherwise there is no way of knowing which missing part is responsible for each function lost. It has so far been impossible to destroy or remove the claustrum alone because of the vast connections it has, and doing so would cause widespread damage to the surrounding brain too.

Some studies have investigated the claustrum in cats, but the results showed the brain cells only responded to individual features rather than combining information. This opposes the theory that the claustrum brings together multiple pieces of information. However, the animals in this study were unconscious, so the results could be interpreted as showing the claustrum actually is involved in consciousness, because it does not function properly when the individual is not awake.

Dutch neuroscientist Bernard Baars uses the analogy of a theatre stage to illustrate consciousness. If a dark stage represents the unconscious mind, then consciousness is like a spotlight of attention on the stage. He views consciousness as a scale from long-term to immediate (or 'working') memory, which is only held for a few seconds while the brain is conscious of the subject. The spotlight is focused on the immediate memory while the rest of the brain's processing takes place in the dark areas of the stage that the person is not aware of.

Memories are made and strengthened by repeated communication between certain neurons. It has been suggested that the continuous use of the same neurons at a given time shows the person is accessing certain memories and therefore becoming conscious of them. Some neuroscientists believe the network of brain cells involved in working memory holds information in the unconscious, and the activity of these brain cells brings it to consciousness.

Are animals sentient?

Evidence suggests we may underestimate the minds of other animals

The ability to recognise one's own reflection is an indication of self-awareness

On 7 July 2012, three renowned neuroscientists published the Cambridge Declaration on Consciousness. This declaration states, "The weight of evidence indicates that humans are not unique in possessing the neurological substrates that generate consciousness." Essentially, three experts in the field told the world that animals are conscious.

The declaration goes on to say that non-human animals have the biological features required for consciousness. For example, most – if not all – mammals have a claustrum; if this is the brain area that controls consciousness, then all mammals must be conscious. The size and complexity of the claustrum (and its equivalent structures in non-mammals) varies significantly between species, which could account for any differences in consciousness among animals. What's more, many species, ranging from birds to apes, are able to recognise themselves in a mirror, showing the self-awareness that features in some definitions of consciousness.

Despite the evidence of consciousness in animals, many still dispute it. This could be because admitting that they have thoughts and feelings like our own makes our treatment of animals (such as in the meat and dairy industries or animal testing) far more unethical and immoral. It's easier not to face moral dilemmas like this by denying animals are sentient beings.

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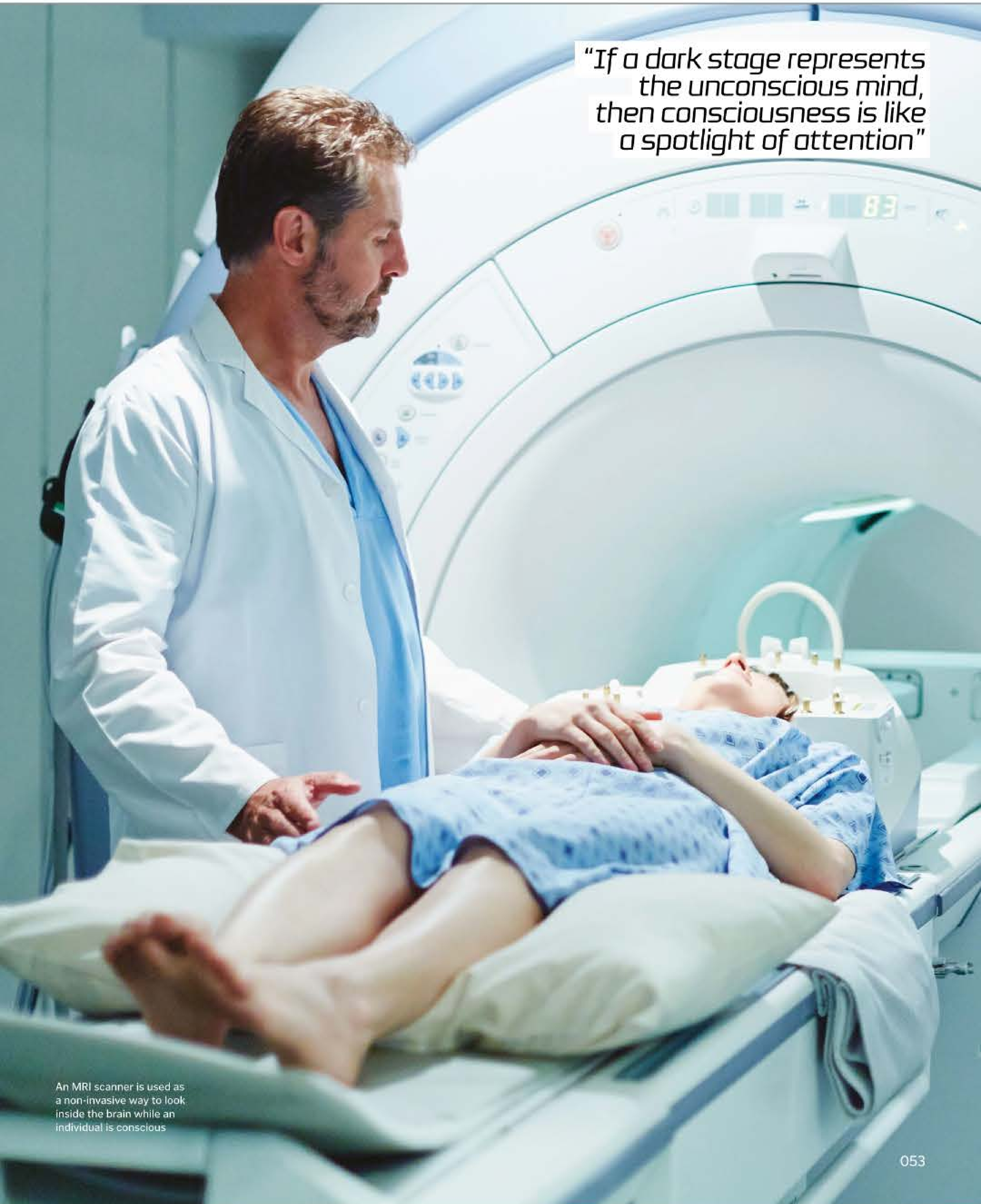


“If a dark stage represents the unconscious mind, then consciousness is like a spotlight of attention”

An MRI scanner is used as a non-invasive way to look inside the brain while an individual is conscious

The importance of understanding consciousness

Knowledge is power, and consciousness is no exception. Discovering more about consciousness would benefit a lot of people

Numerous mental health conditions are based on conscious and subconscious thoughts. For example, people with obsessive-compulsive disorder (OCD) – a broad condition involving repetitive behaviours and routines – may experience intrusive thoughts. These are negative or inappropriate thoughts that occupy their conscious mind. Thoughts like 'Have I locked the front door?' or 'Did I leave the stove on?' can overcome the person, meaning they are unable to think of anything else in that moment.

Post-traumatic stress disorder (PTSD) and personality disorders can arise from people forcing certain distressing thoughts out of their consciousness. This results in unhealthy coping behaviours and leads to unpleasant experiences such as flash-backs, where the upsetting thoughts and images suddenly enter the person's consciousness. Having a greater understanding of what conscious thoughts are and how they come about would no doubt be useful for therapists and could help them treat mental health conditions more effectively.

A better understanding of consciousness could help treat mental health conditions like OCD and PTSD

Sleep is so poorly understood that there are no effective treatments for insomnia. Existing medications are highly addictive and cause hangover-like effects in users. These drugs sedate patients rather than inducing genuine sleep. Scientists cannot truly understand sleep while the unconscious mind remains a mystery.

Numerous studies have shown that people can learn subconsciously, but the reasons behind this are not yet understood. Once scientists unpick the basis of unconscious learning, it could be used to improve the education system. It could also have massive benefits for children and adults with learning difficulties.

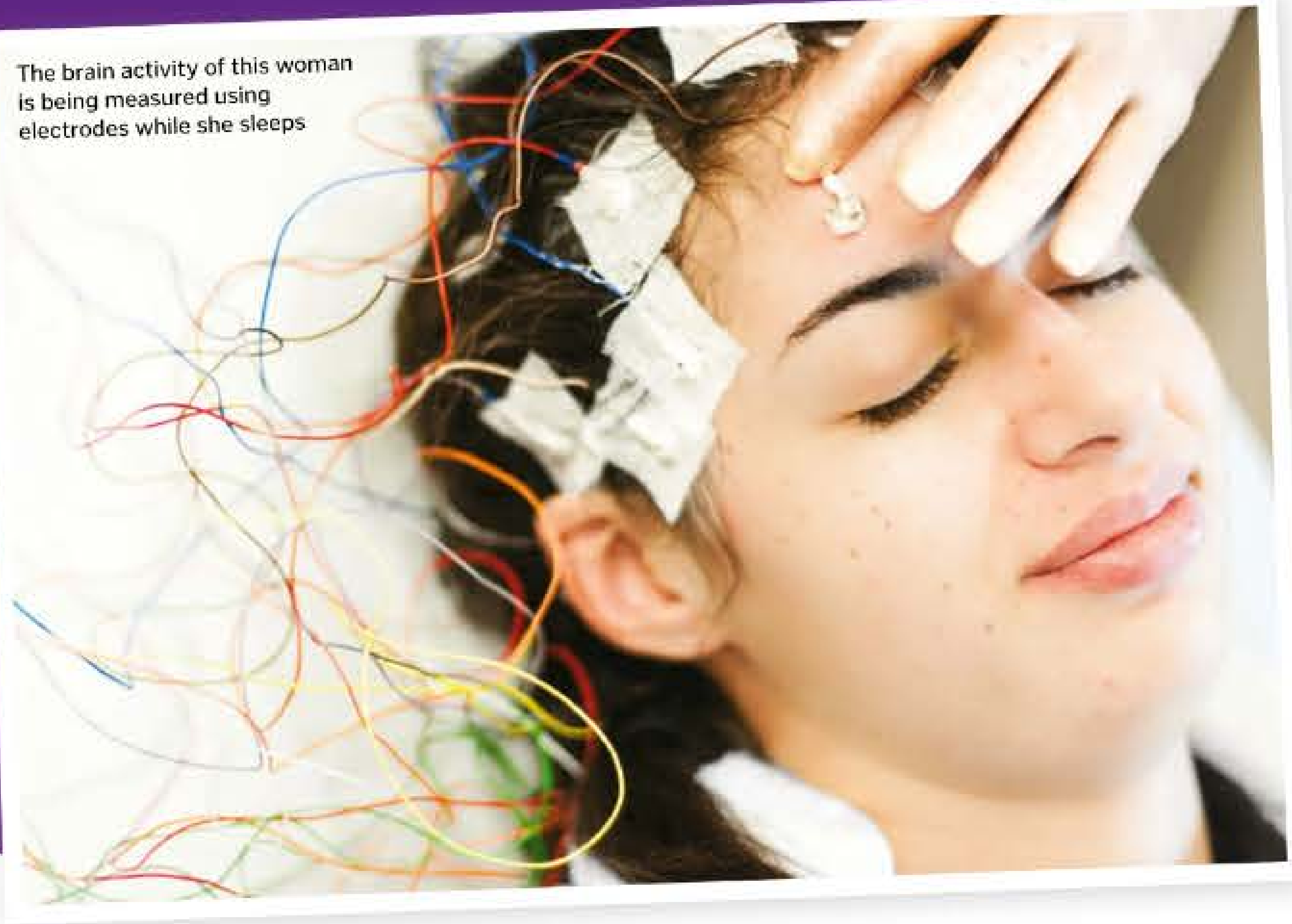
What is dreaming?

During sleep the brain is active enough to conjure up the weird and wonderful things we call dreams

All animals sleep, and most also dream while they're asleep. Live brain scans of humans dreaming show activity mainly in the parts of the brain controlling vision, memory, movement and emotion.

Scientists have proved that dreaming is not just a by-product of sleep but actually has multiple purposes. One function is to cement memories in the brain by re-living them. Interestingly, these memories are replayed without the presence of the anxiety hormone, noradrenaline. This means the emotional impact of memories is removed, so they can be remembered without triggering a negative emotional response. Therefore, dreaming serves to help our mental health by making our memories less painful.

Dreaming also recalibrates the brain. Resetting the processing centres to default allows for more precise functioning the next day in tasks like facial recognition. Additionally, dreams look back on all knowledge learnt and aim to find rules and patterns in it. This is how children learn to use grammar without being able to define what the rules of grammar are. Dreams look at information with a creative eye to interpret it differently – this explains why people often wake up with solutions to problems that stumped their waking brain.



The brain activity of this woman is being measured using electrodes while she sleeps

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Creating truly intelligent machines would raise many ethical questions

Artificial consciousness

We make machines that can walk or talk like us... but could they ever think like us?

Conscious artificial intelligence may become a reality in the not too distant future

Learning is no longer unique to living beings. Artificial intelligence (AI) is the ability of machines to perform tasks that would ordinarily require human intelligence, such as recognising faces or calculating sums. It has already proved invaluable for things like cybersecurity.

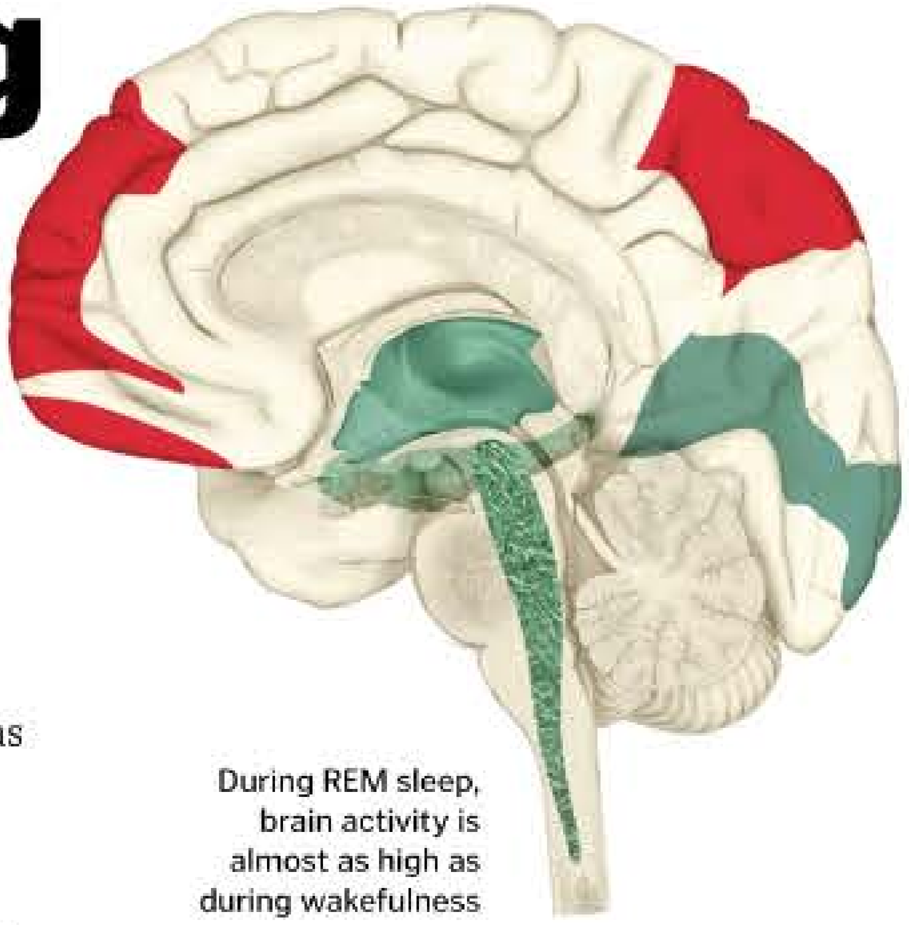
Intelligence, artificial or natural, is formed through learning. Machines are taught in much the same way as dogs are taught new tricks: with punishment and reward. The computer is taught the concept of punishment and reward and then, instead of bone-shaped biscuits, it receives virtual rewards for correct responses. But if a system can understand the concept of punishment, then can it feel suffering? If a machine did not like what was being done to it, and had sufficient learning ability, could it break free and seek revenge? Would the creators of AI be responsible for its wellbeing like a parent is responsible for that of their child? If AI can suffer, does it deserve to have rights?

AI is already used in home personal assistants, like Amazon's Alexa, which act as companions to many people. For example, some people with dementia use systems like Alexa to help them perform daily tasks and answer their repeated questions. This can provide vital respite and a sense of security to those caring for them. Conscious AI could give an even more interactive and personal experience for these people. Would you deny someone who is socially isolated the chance of a companion because of the ethics of what is essentially an electronic slave? The NHS classes dementia as a 'disorder of consciousness', so who takes priority: the partially conscious human or the fully conscious machine?

These questions have been fiercely debated by professionals and the public, but so far they are purely hypothetical. While AI is still programmed by humans rather than making its own decisions, it is not considered conscious. Thinking back to the levels of consciousness, AI can currently only operate at the most basic level, C0, which is processing that happens subconsciously in humans. Because scientists are yet to fully understand consciousness, they can't replicate it in machines, although this reality is not far away. Once scientists figure out how human consciousness is achieved, the same equations already used in simpler AI tasks can be transferred to produce consciousness. Therefore, the potential benefits and risks associated with a sentient form of AI must be balanced before it is developed and the issues are upon us, at which point it will be too late to turn back.

Dissecting our dreams

Far from resting, our brains are working hard while we sleep



During REM sleep, brain activity is almost as high as during wakefulness

At the end of a long day, there's nothing as inviting as a cosy bed. After little sleep the night before, a day packed with activity or hours of solid concentration, it can become a challenge just to keep your eyes open. Most people are lucky enough to sleep comfortably and safely, but becoming unconscious and paralysed put our ancestors at risk of attack from enemies and animals. The benefits must have outweighed the dangers, but why did humans evolve to spend so much of their lives asleep in the first place?

The real answer is that no one's completely sure. While we've moved on from Lucretius' theory of ominous air particles attacking the spirit each night, many of the exact details about our time spent slumbering remain a mystery. What we do know is that sleep is vital for our health and that a total lack of it is dangerous, leading to effects like hallucinations and eventually death.

We often think of sleep as a time when the brain and body are dormant and still, but a lot goes on while we're snoozing. One of the most important functions of sleep is allowing the brain time to process information. Even in a seemingly boring day you're taking in huge amounts of information, and the brain needs to sort through the data, make connections, throw out anything unimportant and file the rest neatly away. Sleep gives the brain a chance to convert or consolidate short-term memories and scraps of useful information into long-term memories by strengthening neural connections.

All this processing goes partway to explaining why children – and baby animals of most species, for that matter – need so much more sleep than adults. As well as requiring lots of energy for physical growth, babies and children are constantly faced with new information and things that need remembering. To function and develop optimally, a one-year-old child needs to sleep for 11 to 14 hours a night.

Adults should aim for seven to nine hours of sleep, but many people average much less. Side-effects of sleep deprivation include grumpiness, clumsiness, difficulty concentrating and forgetfulness. Trying to recover, regions of the brain can become inactive and fall into a localised sleep while a person is awake. The extremely sleep-deprived can even slip into microsleeps, lasting about a second and often going unnoticed.

While their brains grow and learn, babies need to spend a lot of time asleep

10 most common dreams

According to some, sleeping brains reveal secrets about our waking lives

Falling
Fear of failure or change, reconsidering a choice, clinging too tight.

Flying
Feeling free and confident or wanting to escape a certain situation.

Being chased
A desire to escape from a situation, feeling, memory or person.

Teeth falling out
Worry about appearance, rejection, powerlessness or saying the wrong thing.

Pregnancy
Personal development, new ideas or fear of new responsibilities.

Naked in public
Insecurity, worry about true self or shortcomings being exposed.

Failing an exam
Low confidence in abilities, fear of the next big step, work stress.

Out-of-control vehicle
Not being on the right track in life, losing control.

Finding an unused room
Discovering a new side to yourself or a new talent.

Unable to find a toilet
Being unable to express or meet your own needs.

Why do we dream?

Humans love sharing and interpreting their dreams, but their purpose is debated

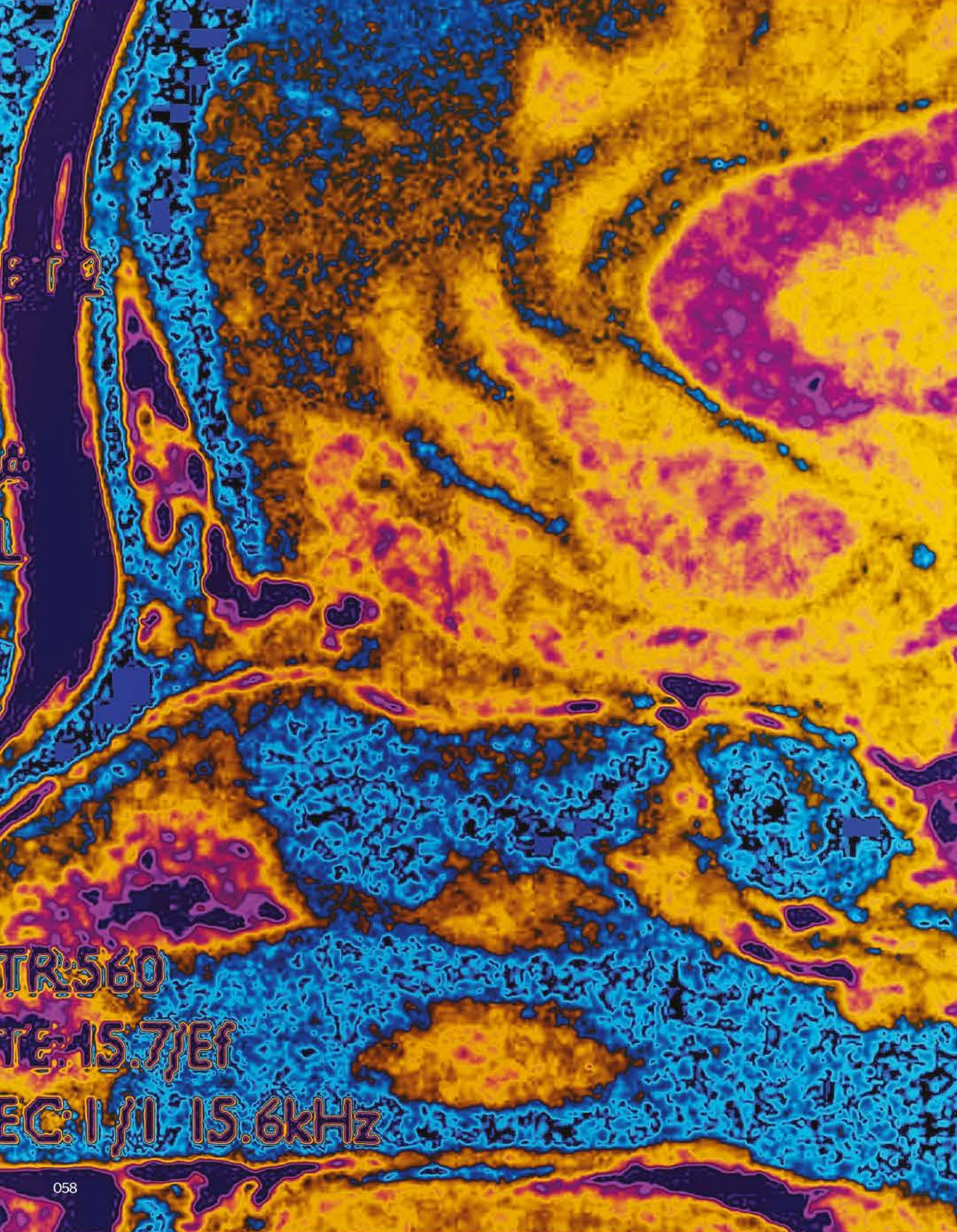
Dreams range from the mundane to the fantastical. The average person has between three and six dreams a night, although they'll only remember about five per cent of them. They can occur during any of the five stages of sleep, but the most vivid and detailed take place during rapid-eye movement (REM) sleep, when the brain is at its most active.

During REM sleep it's usually only the eye muscles that move, which can lead to people feeling paralysed and trapped in particularly vivid nightmares or stressful dreams. People with certain conditions or dreaming during other stages of sleep, however, can talk or move in their sleep, and they sometimes even act out their dreams.

There are various theories about the purpose (or lack thereof) of dreams. These include the brain using dreams to connect experiences from the day to existing memories, or as a space for addressing thoughts and feelings that are too overwhelming to deal with during the day. It could also be the sleeping brain randomly interpreting electrical signals, or dreams revealing secret thoughts suppressed when a person is awake.

Another idea is that dreaming prepares us for the future. By combining different memories, the brain can piece together a simulated scenario that a person hasn't experienced yet to address potential dangers or work out what to do in this imagined situation.

Dreams experienced during REM sleep can feel remarkably real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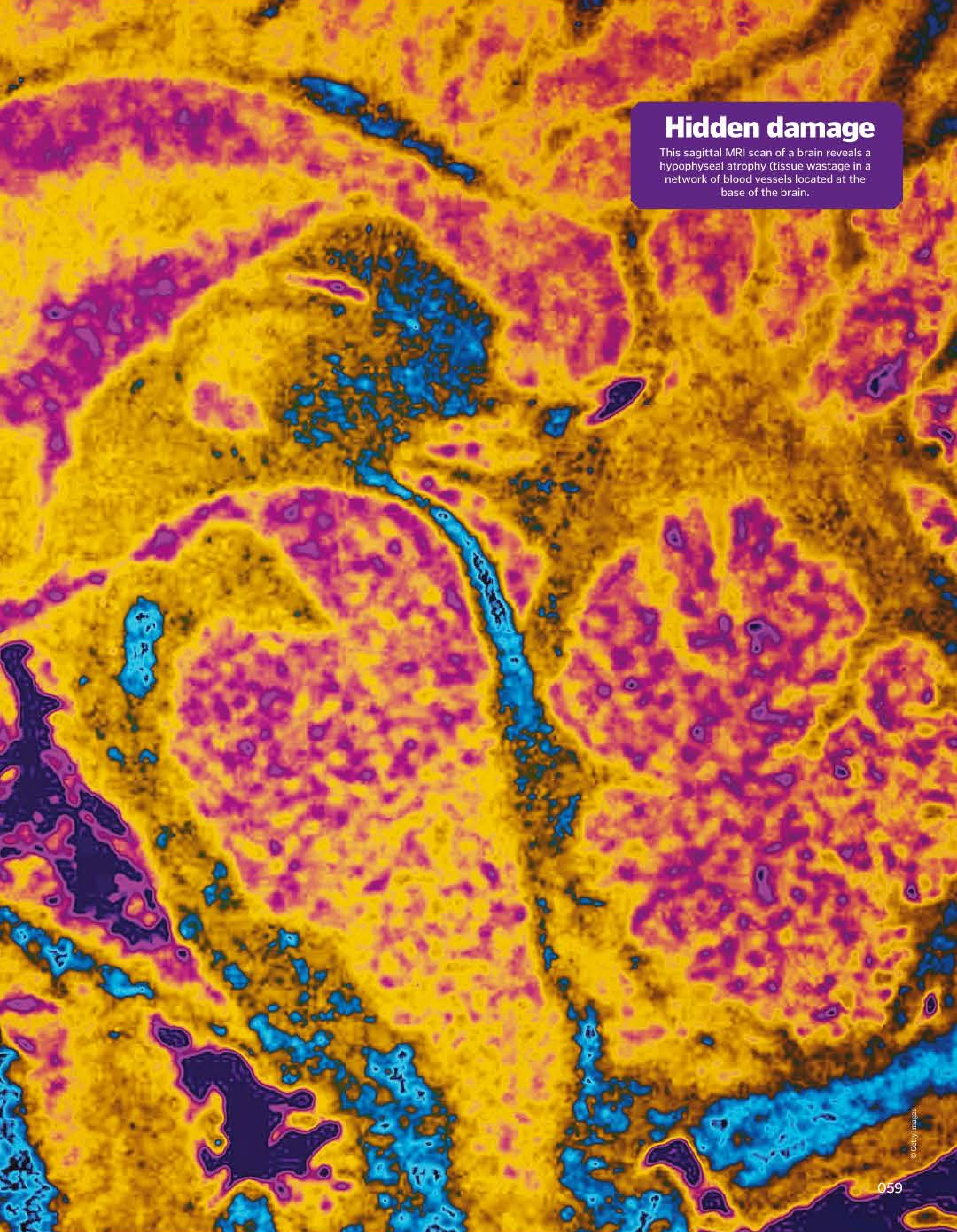


Hidden damage

This sagittal MRI scan of a brain reveals a hypophyseal atrophy (tissue wastage in a network of blood vessels located at the base of the brain.

© Getty Images

Music has a powerful influence on the brain

Your brain on music

What happens inside your head when you are listening to your favourite tunes?

Brains are complex, as is music, so teasing out the neurological response to melodies is something of a challenge, but researchers across the world have been working to demystify the baffling science behind it.

The first components of music to be processed by the brain are the basic sounds – pitch, length and volume. From this, the brain then teases out melody and distinguishes between different instruments. This information is then compared to memories, establishing whether the incoming sound is familiar and revealing any linked emotions. All together, the processing leads to a response, whether that's switching the song off or starting to dance. And if you move, that feeds back into your brain again, affecting the experience even further.

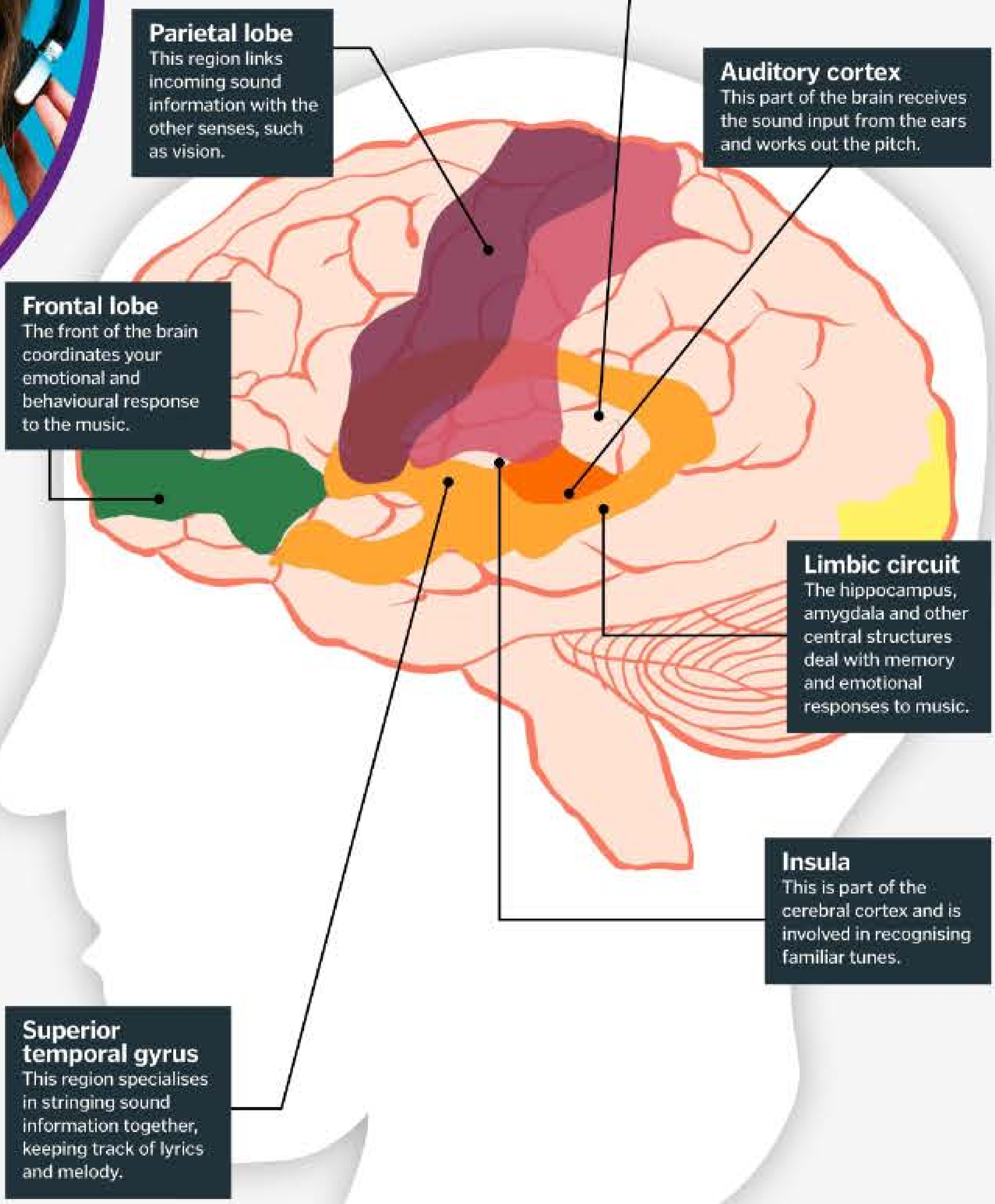
Some of the complexities of the brain's response to music can be revealed by people with damage or injury to their brains. By seeing what happens to the ability to process music after the brain is injured in a certain place, and by observing how that improves as the brain heals, scientists can start to piece together which parts of the brain are involved. This is aided by advanced imaging technology, such as functional MRI scanners, which can monitor the activity in different parts of the brain in response to music.

One major revelation from this kind of work is that music is separate from language. Aphasia is the medical term for a neurological disorder that results in difficulty speaking. It can happen as a result of a brain injury, like a stroke, and makes it challenging for people to find the words that they need to express themselves, but strangely it doesn't always interfere with their ability to sing. Similarly, people with a stammer may struggle with speech but can sometimes sing a song without hesitation.

Around one in 20 people is tone deaf, or 'amusical', and has trouble identifying the notes in a tune. Brain scans have revealed that the white matter in the area involved in processing sound is thinner in these individuals, indicating that it could be less well connected than the same pathways in their musical counterparts.

Processing music

Different areas of your brain come together to handle rhythm, melody, lyrics and emotion



Planum temporale
This area deciphers complex sounds, picking out rhythm, timbre and patterns.

Parietal lobe
This region links incoming sound information with the other senses, such as vision.

Auditory cortex
This part of the brain receives the sound input from the ears and works out the pitch.

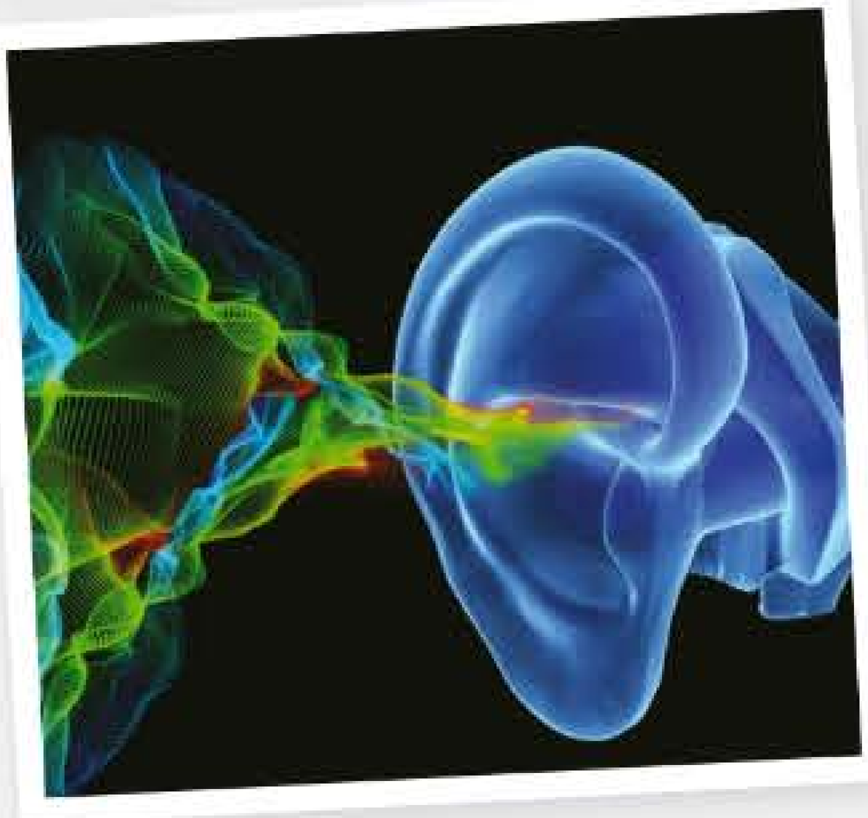
Frontal lobe
The front of the brain coordinates your emotional and behavioural response to the music.

Limbic circuit
The hippocampus, amygdala and other central structures deal with memory and emotional responses to music.

Insula
This is part of the cerebral cortex and is involved in recognising familiar tunes.

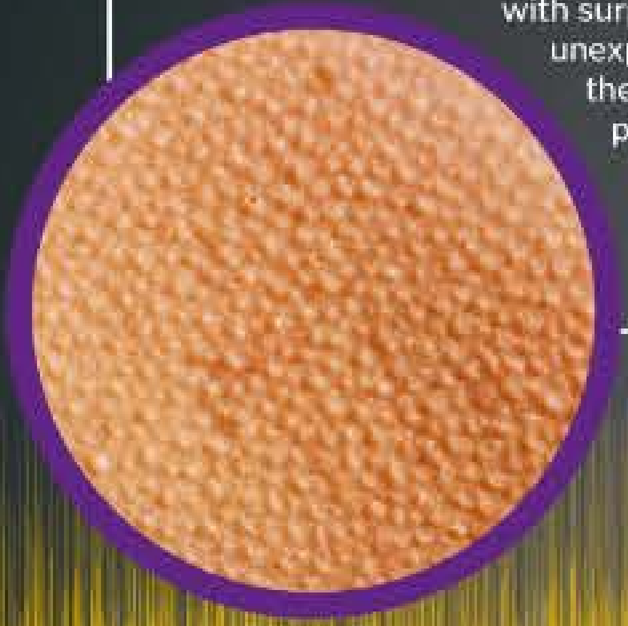
Superior temporal gyrus
This region specialises in stringing sound information together, keeping track of lyrics and melody.

The music entering your ears is just the beginning



Why does music give you 'chills'?

Good songs can make your hairs stand on end, and this is thought to be triggered by the way that our brains are wired. Music taps into the parts of the brain involved with emotion and reward, and listening to certain tunes can light up the same areas tickled by food and even drugs. At the same time, music seems to decrease the activity in the areas of the brain involved in fear. Getting goose bumps is linked to arousal of your autonomic nervous system, which comes hand in hand with an increase in heart rate and deeper breathing. Researchers looking into exactly what triggers this think that it might have something to do with surprise; unexpected shifts in the music are particularly good at setting off this response.



Why do we tap our feet to music?

The urge to tap your foot along to a strong beat is often irresistible. It was previously believed that our movements in response to music reflect how we perceive that it was created – a tapping foot imitates a drummer's pedal, for instance – or our mood upon hearing the music. However, more recent research suggests that tapping your foot may influence the way you perceive the music, helping your brain to process what you are hearing.

What makes songs so catchy?

Researchers have an interesting way to describe this phenomenon – they sometimes refer to it as a 'brain itch' or an 'earworm'. Some songs seem to get stuck in people's heads more often than others, but there is not a simple formula that determines catchiness. Researchers working in the field have noticed that catchy songs tend to have short, repetitive sections, and they also often have some connection to the listener. A similarity to a song that you already know, or a cultural connection – such as lyrics that you can relate to – both help to get a tune stuck in your head. Ultimately though, a song that is catchy to one person might not be for another.

Why does your singing sound better in the shower?

This is down to acoustics. If you sing in a big room with plastered walls, the sound travels a long way before it reaches an obstacle, and a lot of the vibration is absorbed. In a bathroom, the room is smaller, and the tiles or glass reflect the sound back at you in all directions. This creates reverberation. The result is that the sound is louder, and the multiple reflections help to even out any tiny mistakes in your voice. The size of the shower cubicle also has a part to play – lower frequencies tend to be amplified more than higher ones, making the voice sound richer.

"Around one in every 20 people is tone deaf"

What are the origins of music?

People have been making music for millennia, and the oldest known instruments date back 42,000 years. They are bone and ivory flutes, discovered in a cave in Germany alongside other early human art and ornaments. However, it's generally believed that music was around a long time before the first instruments, as people used their voices to make melodies. Being able to produce music could have helped with social bonding, an idea that is sometimes described as 'vocal grooming'. These kinds of cultural advances are thought to have given our species an edge over our human-like cousins, including Neanderthals.

Music has been a part of human culture for thousands of years

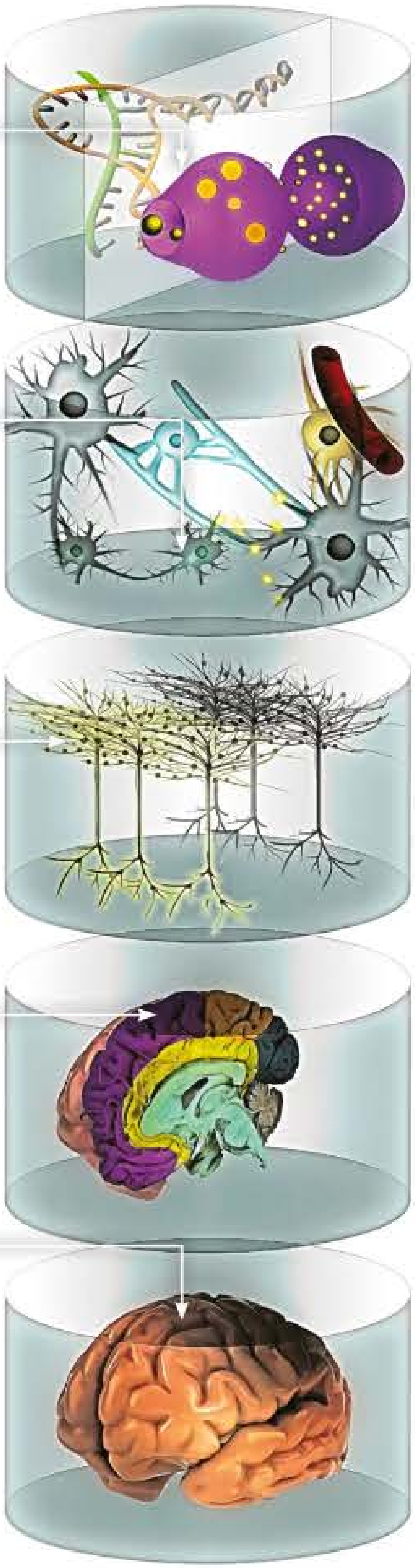
© Thinkstock; Illustration by Rebekka Hearl; Getty

Cutting-edge neuroscience

The human brain is one of the most complex structures in the known universe and understanding how it works is an enormous scientific undertaking. Modern neuroscience brings together experts from a huge array of fields, and by using a combination of the most advanced technologies, medical techniques, biological research and computational modelling, scientists are finally beginning to untangle the many profound mysteries of the brain.

Building a brain

Large-scale projects aim to simulate the human brain at every level



DNA and neurotransmitters

At the molecular level, scientists are able to manipulate the 3D structures of proteins using computer programs and to model the effects that changes might have. Such techniques are hugely useful in drug design.

Nerves and support cells

In order to gain a proper understanding of how the brain functions, many scientists advocate a bottom-up approach. By creating digital neurons based on the underlying rules and principles of biology, it is hoped that the complex network of the brain can one day be simulated.

Neural pathways

Some projects aim to map all of the connections in the human brain, generating a 3D representation of the intricate wiring. Others aim to simulate the process, allowing the computer to make its own connections based on biological rules.

Lobes and structures

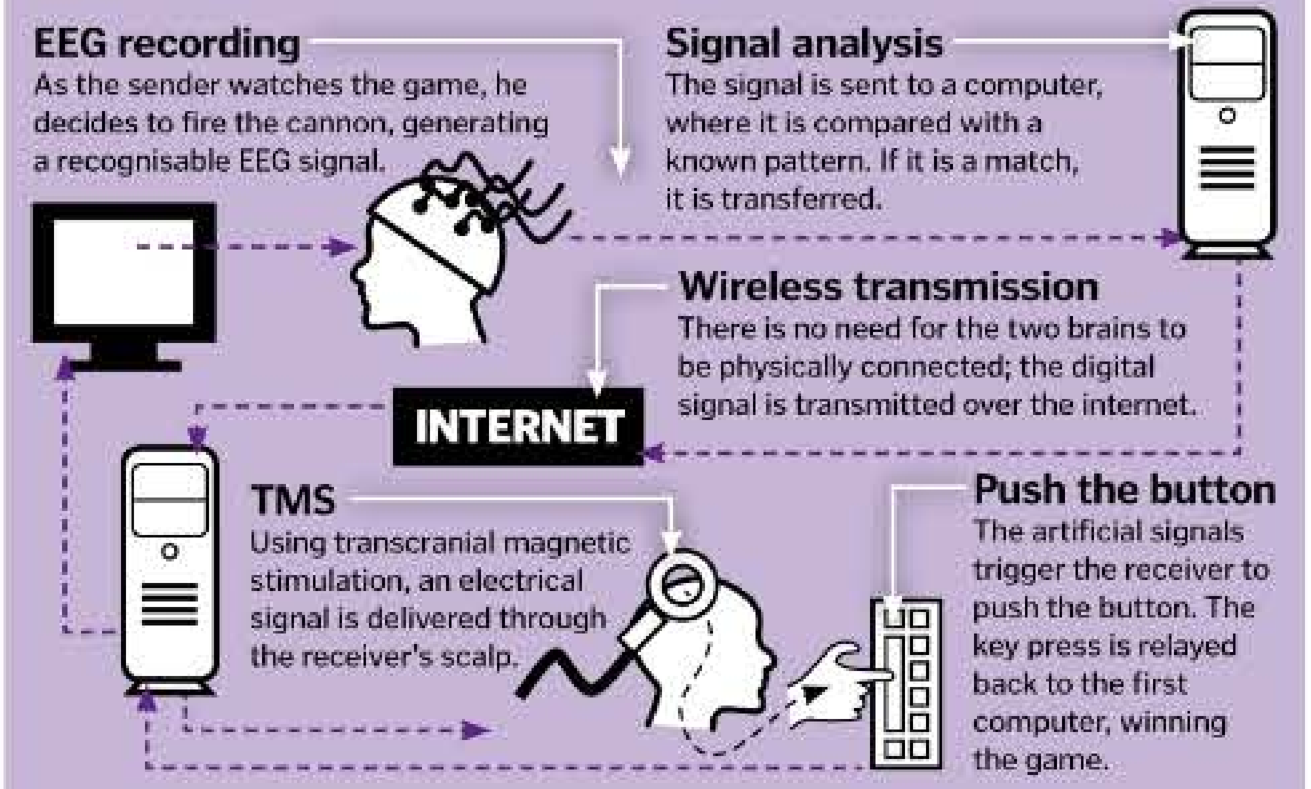
Simulations will allow information about different structures in the brain to be integrated, enabling scientists to more closely examine the interactions between different areas or even to remove one region and study it in isolation.

Whole brain

In 2013, the K Computer in Japan carried out one second of simulated human brain activity. With 705,024 processor cores, it took the machine 40 minutes to simulate a network just one per cent of the size of the human brain. Advanced processors due in the next ten years will increase this capability significantly.

How mind control works

Simple equipment and complex computer programming allow our thoughts to be transmitted over the internet



EEG recording
As the sender watches the game, he decides to fire the cannon, generating a recognisable EEG signal.

Signal analysis
The signal is sent to a computer, where it is compared with a known pattern. If it is a match, it is transferred.

Wireless transmission
There is no need for the two brains to be physically connected; the digital signal is transmitted over the internet.

TMS
Using transcranial magnetic stimulation, an electrical signal is delivered through the receiver's scalp.

Push the button
The artificial signals trigger the receiver to push the button. The key press is relayed back to the first computer, winning the game.

Mind control

In a groundbreaking experiment in 2013, researchers at the University of Washington successfully linked two human brains together and proved their principle with a video game.

A city is under attack by pirates and player one, the sender, must intercept their rockets. They can see the screen and are armed with a cannon, but they do not have a keyboard and cannot press 'fire'. Player two, the receiver, is sitting in another room; he cannot see the game, but he does have a keyboard. Player one thinks about firing the cannon, and fractions of a second later, player two pushes the button, saving the city and winning the game.

Player one was wired up to an electroencephalogram (EEG) and his brain activity was being monitored. When he was thinking about pressing the button, there was a characteristic signal in the 'mu band' of the EEG, triggering the program to send a wireless signal to player two.

Player two was wearing a specially designed coil on his scalp that generated a magnetic field, positioned over the part of the brain that controls contraction in the right hand. The signal from player one was converted into magnetic stimulation, which in turn triggered electrical activity in the brain, causing player two to involuntarily fire the cannon.

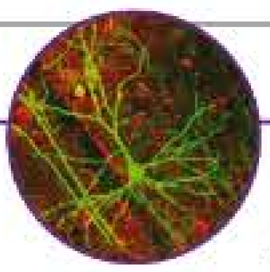
KEY DATES
HISTORY OF NEUROSCIENCE

1700 BCE
An Egyptian surgeon records details of his patients, producing the first written example of the word 'brain'.

130-200 CE
Greek surgeon Galen suggests the brain is responsible for sensory perception and the control of movement.

1837
Czech Johannes Purkinje describes a nerve cell for the first time; the large, branching neurons of the cerebellum.

1861
Pierre Paul Broca identifies the region of the brain responsible for speech, now known as 'Broca's area'.



1906
Camillo Golgi and Santiago Ramón Y Cajal share the Nobel Prize for demonstrating that the brain is a network of neurons.

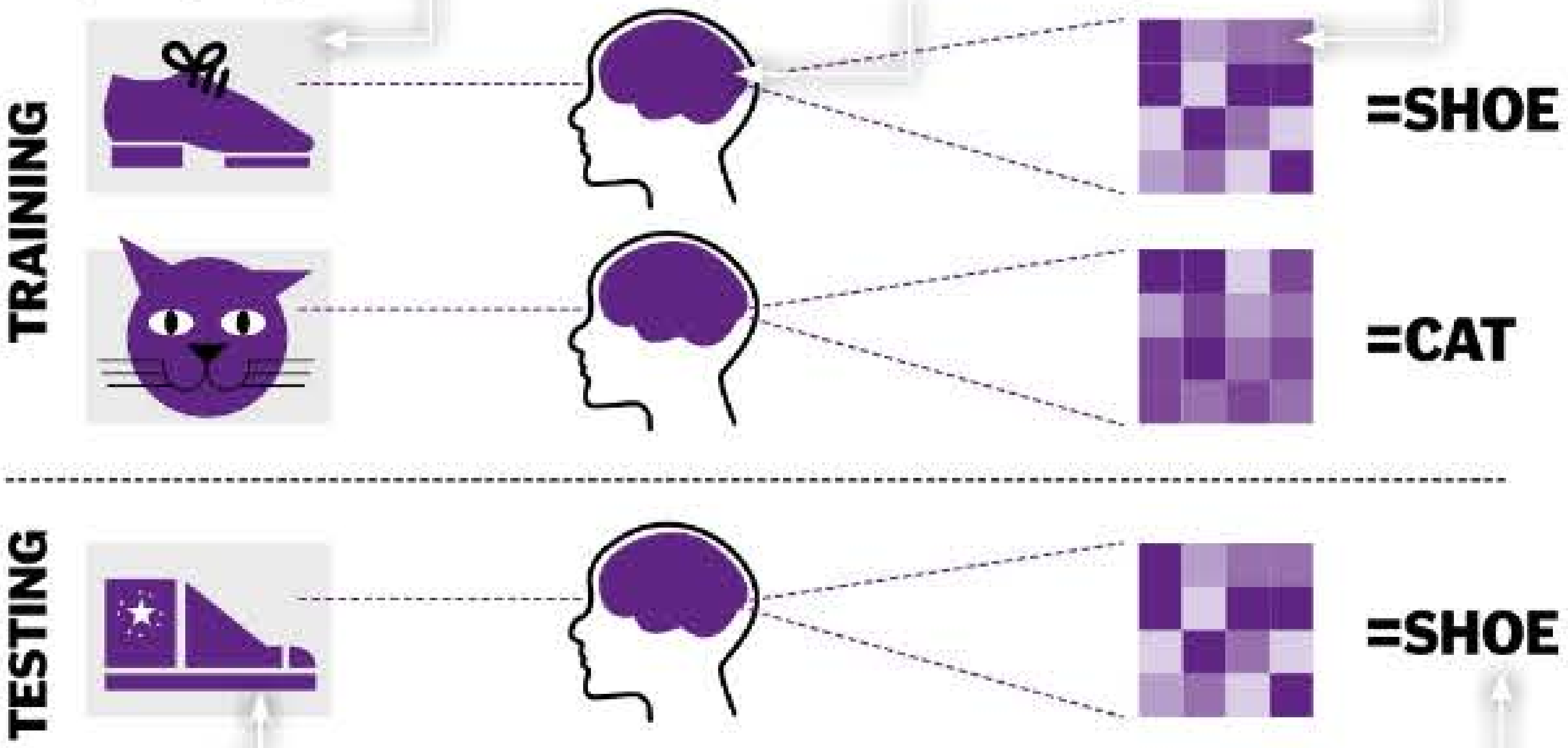
Decoding the brain

Computer programs can learn to decode brain-scan data and essentially read our thoughts

Training images
The program is trained using a series of images, alongside their corresponding fMRI patterns.

fMRI scan
Functional magnetic resonance imaging is used to identify the parts of the brain activated by different visual stimulation.

Voxel pattern
The fMRI data is stored as voxel patterns, three-dimensional grids of information.



Test image
When the subject is shown a new image, the program searches through its training database to find the nearest match.

Identification
If the program cannot find an exact match, it will use its training data to find a best estimate.

A machine that can read your mind

Have you ever wished someone else could see what you can see? A team at the University of California, Berkley, have developed a program that can tell what film you are watching just by reading your brain activity. The program can even read the exact image you see and display the moving mental images on a screen.

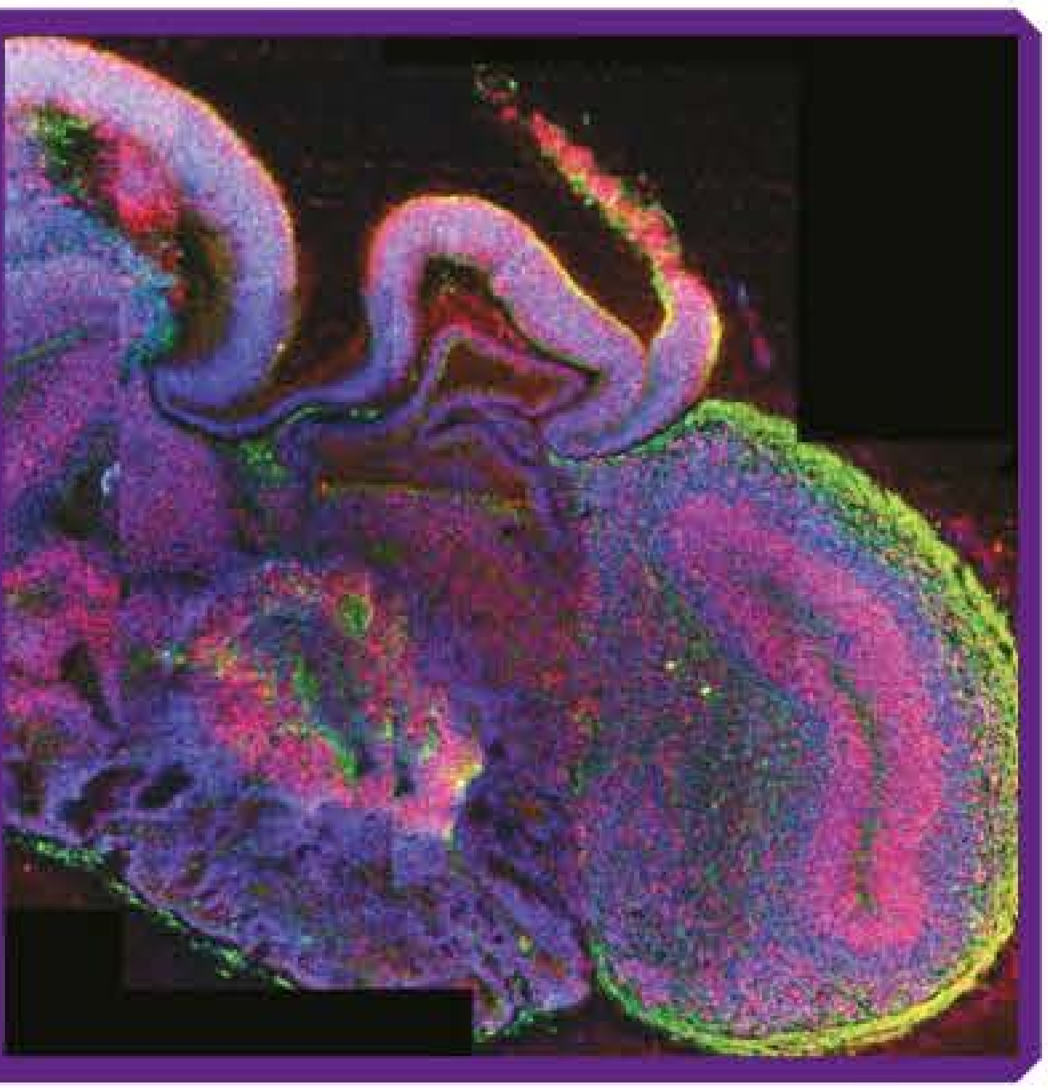
Volunteers were shown hours of video clips and for each one their brain activity was mapped using functional magnetic resonance imaging (fMRI). The program was then trained to associate patterns of brain activity with their corresponding images.

Using this data set as a reference, the program was then shown new fMRI data recorded as people watched unknown clips. The program was able to compare the new data against its training data and guess what the test subject was watching by compiling and averaging the closest matches into moving collages. The resulting pictures were eerily close to the original clips.

Growing a brain

In 2013, scientists at the Austrian Academy of Sciences achieved something incredible: they grew part of a human brain in a Petri dish. Using a combination of embryonic stem cells and stem cells taken from adult skin, the team recreated the neuroectoderm, the embryonic structure that goes on to form the brain and the spinal cord.

The cells were put in three-dimensional scaffolds to give them something to grow around and then given nutrients and oxygen and allowed to develop. Amazingly, the structures organised themselves into something resembling the brain of a nine-week-old foetus. Some contained the pigmented cells of a retina, others developed a cortex, and some even had a hippocampus. These mini-brains were about the size of a pea and incapable of thought, but they provided a valuable tool for researchers.



Get involved with EyeWire

Citizen scientists are needed to help untangle the neurons of the human retina

Developed by the Seung Lab at MIT, this browser-based game, known as EyeWire, is a project designed to map the neurons of the retina. Anyone can play; all you need is a computer and an internet connection.

EyeWire is a 3D puzzle game based inside a cube. The cube is divided into slices and hidden within them is the path of a neuron. All you have to do is scroll through and connect the slices together, tracing the path of the nerve cell through the cube.

As you work, a 3D model of your progress appears to the side of the screen, and you can earn points based on how closely your model matches the models made by other players. You can earn points, level up and even participate in weekly competitions.

Every time you play, you are mapping actual neurons from the human retina, making a real contribution to scientific research.

Korean scientist Sebastian Seung is the pioneer behind EyeWire

© Thinkstock; Dreamstime; Science Photo Library; Madeline A. Lancaster; University of Washington

Brain surgery

If you thought rocket scientists had to pay attention to detail, wait until you meet this lot…

There is still so much we don't know about the human brain. However, if something goes wrong and it needs an operation, you will find yourself in need of a neurosurgeon. These guys can operate on the vast number of structures within the brain and spinal cord and have a full arsenal of techniques and – literally – cutting-edge technologies to hand.

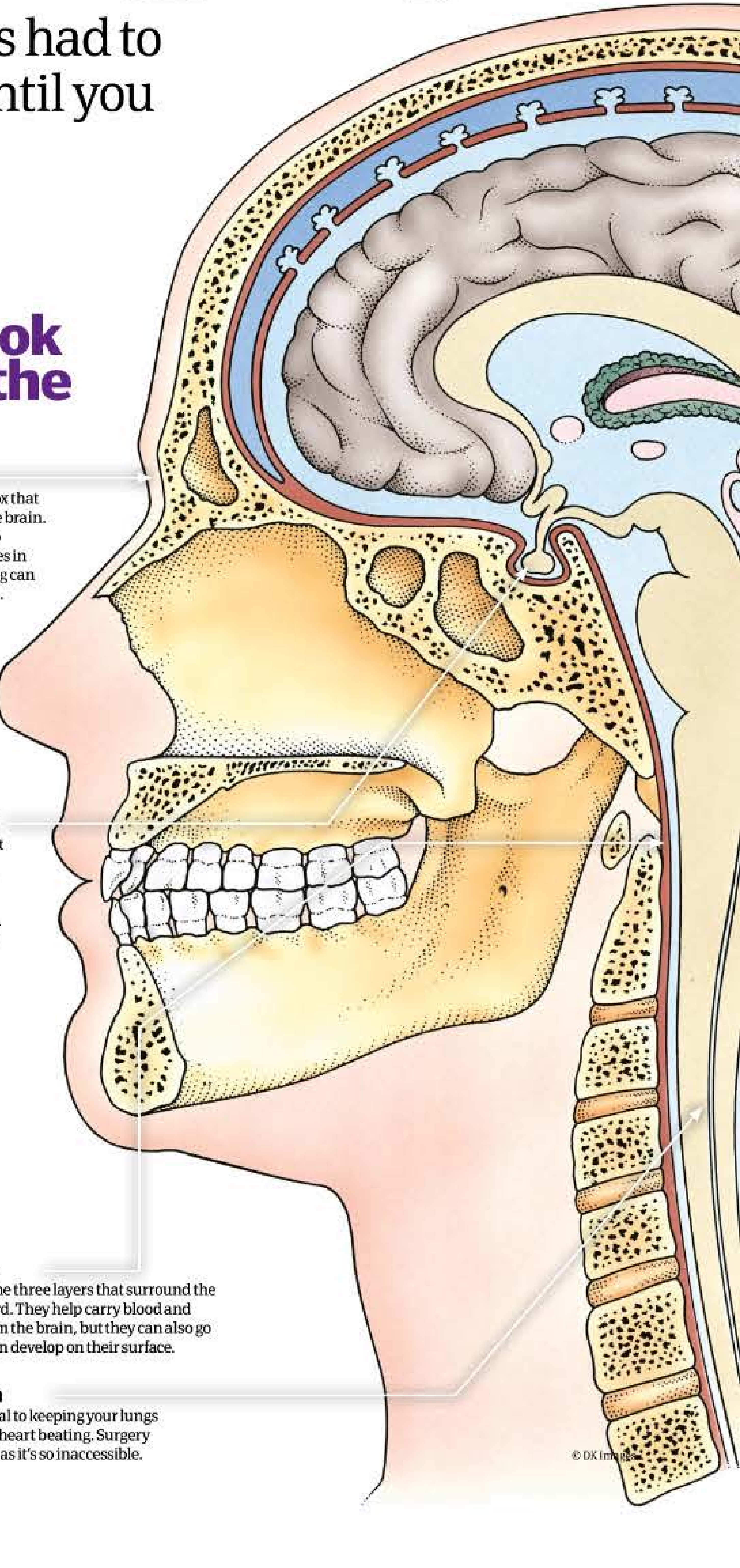
A neurosurgeon's workload comes in two main forms. The emergency work is often a result of road traffic accidents or fights and often affects young men with head injuries. These patients may have bleeding within the skull, which is exerting pressure on the brain – the neurosurgeon must relieve that pressure. There is also the planned work, where neurosurgeons try to remove tumours without causing any damage to surrounding structures.

The technology starts a long way before the operation. Advanced CT and MRI scans allow for 3D reconstructions and images that we couldn't have even dreamed of a few years ago. This allows neurosurgeons to plan the precise timing and nature of surgery – where to cut and how deep to make the incision. The imaging falls within a team approach to caring for these patients, as the team is just as important as the technology.

Surgery is becoming less invasive as time goes on. The advantages of this are smaller incisions, less disruption to surrounding tissues, less pain and shorter hospital stays. Surgeons now often use powerful microscopes with bright lights to help them remain as precise as possible. These microscopic techniques require a huge amount of

Famous American neurosurgeon Sanjay Gupta at work

Let's look inside the skull…



The skull
The skull is a rigid, bony box that surrounds and protects the brain. However, it won't stretch to accommodate any increases in pressure inside, so bleeding can rapidly compress the brain.

The pituitary gland
The pituitary is a gland that helps regulate the hormones in your body. If it's producing too many hormones and won't settle, surgery can be carried out on it… via the nose.

The meninges
The meninges are the three layers that surround the brain and spinal cord. They help carry blood and nutrients to and from the brain, but they can also go wrong – tumours can develop on their surface.

The brainstem
The brainstem is vital to keeping your lungs breathing and your heart beating. Surgery here is very difficult as it's so inaccessible.

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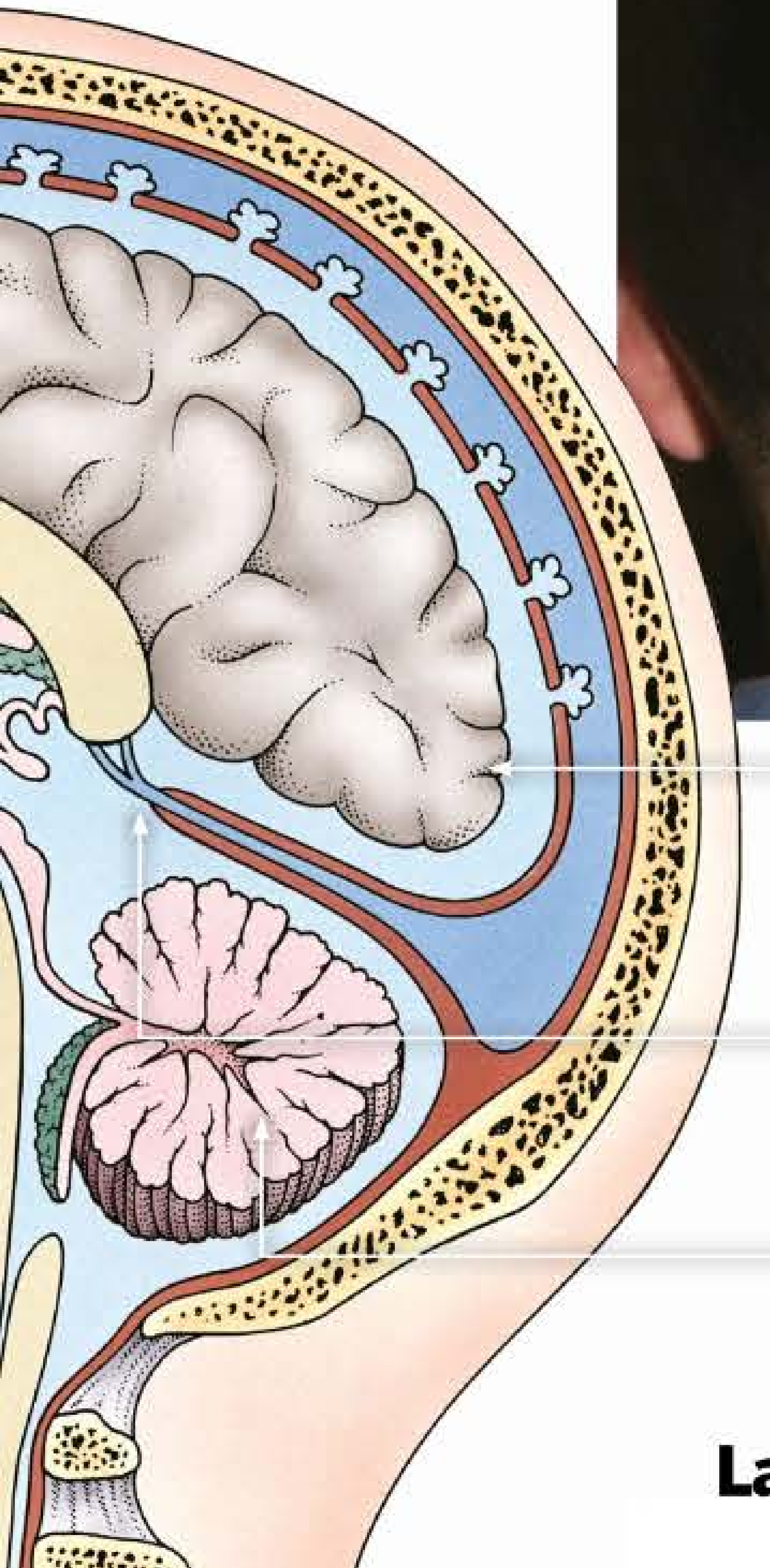


The grey matter

The grey matter contains complex areas of memory, personality and function. Surgery here can have few effects or it can have devastating effects, such as taking away your memories or changing your personality.

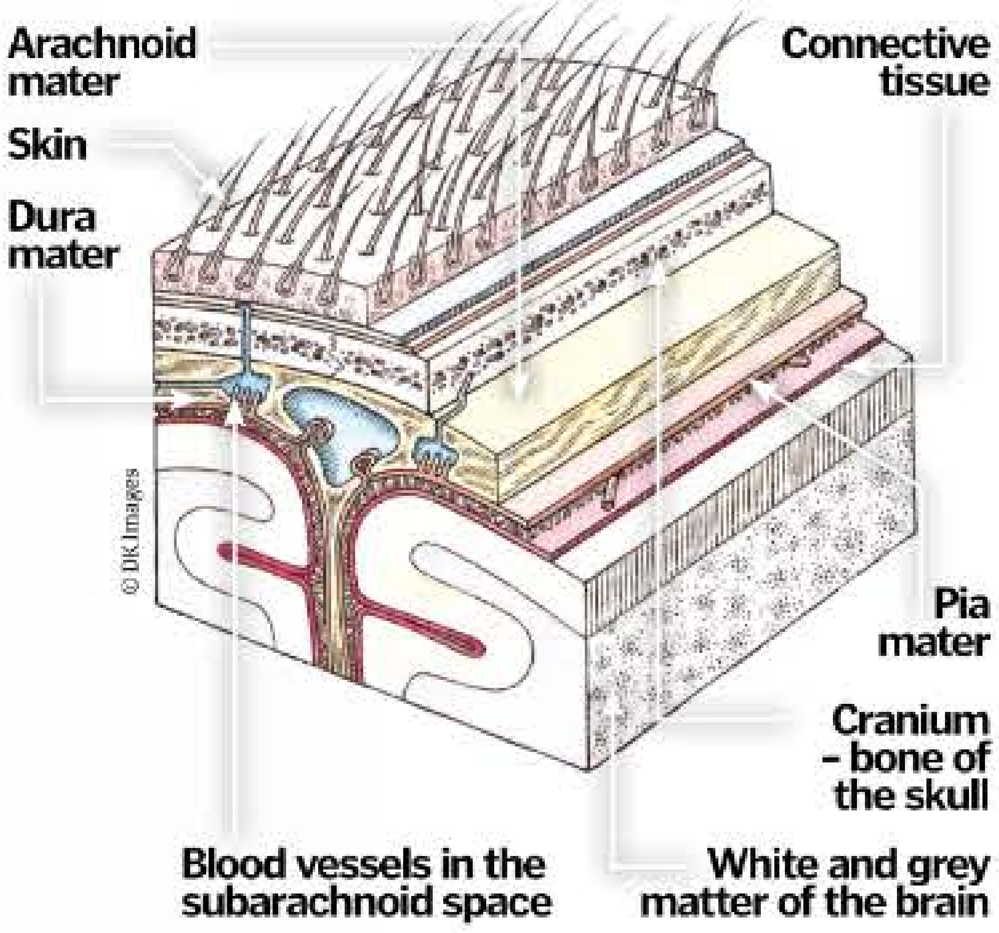
The ventricles

The ventricles allow a special fluid – cerebrospinal fluid – to circulate around the brain. If they get blocked the brain can swell rapidly, and the pressure can cause headaches as the meninges stretch.

The cerebellum

The cerebellum controls your fine movements. Surgery here can leave you with balance problems.

Layers surrounding the brain


Arachnoid mater
Skin
Dura mater
Connective tissue
Pia mater
Cranium – bone of the skull
Blood vessels in the subarachnoid space
White and grey matter of the brain

© DK Images

> *"CT and MRI scans allow for 3D reconstructions we couldn't have dreamed of a few years ago"*

Why do you need brain surgery?

Some of the common reasons for performing brain surgery

Trauma

Often following road traffic accidents or fights, head injuries are common – especially in young men. They can range from minor to life-threatening. Sometimes surgery won't help, but if the bleeding can be stopped in time, you need a neurosurgeon.

Appropriate procedure: Craniotomy
Procedure length: 1–4 hours
Recovery time: Weeks to months
Effectiveness of procedure: If early enough completely effective. If late it can be devastating.
Severity of condition: ■■■■■ **Difficulty of surgery:** ■■■□□

Tumours

Brain tumours present themselves in a variety of ways – some people have headaches, some have co-ordination problems, and some have no symptoms at all. Metastatic tumours, where growth is from another source (such as breast or bowel), are the most common type.

Appropriate procedure: Craniotomy or stereotactic surgery
Procedure length: 2–12 hours
Recovery time: Weeks
Effectiveness of procedure: Ranges from no effects to severe effects.
Severity of condition: ■■■■■ **Difficulty of surgery:** ■■■■□

Cerebral aneurysms

Swellings in the fine blood vessels within the brain can burst, leading to devastating bleeding. Preventing the bleeding is the trick here.

Appropriate procedure: Endovascular coiling
Procedure length: 1–3 hours
Recovery time: Days
Effectiveness of procedure: If coiled before a major bleed, it's likely to provide an excellent outcome.
Severity of condition: ■■■■□ **Difficulty of surgery:** ■■□□□

Epilepsy

Surgery for epilepsy isn't for everyone. In some cases, where medicines can't control the fits, surgery may be appropriate if the fits are arising from one area.

Appropriate procedure: Temporal lobectomy
Procedure length: 2–4 hours
Recovery time: Days
Effectiveness of procedure: There is a 95 per cent chance of success in selected patients.
Severity of condition: ■■□□□ **Difficulty of surgery:** ■■■□□

Parkinson's disease

Some patients with Parkinson's disease will benefit from some extra stimulation of their nerves. Implanting a special nerve 'pacemaker' isn't easy, but this deep brain stimulation can produce stronger signals.

Appropriate procedure: Deep brain stimulation
Procedure length: 2–4 hours
Recovery time: Days
Effectiveness of procedure: Medium to good.
Severity of condition: ■■■□□ **Difficulty of surgery:** ■■■■□

skill, dexterity and hand-eye co-ordination that would impress even a fighter pilot.

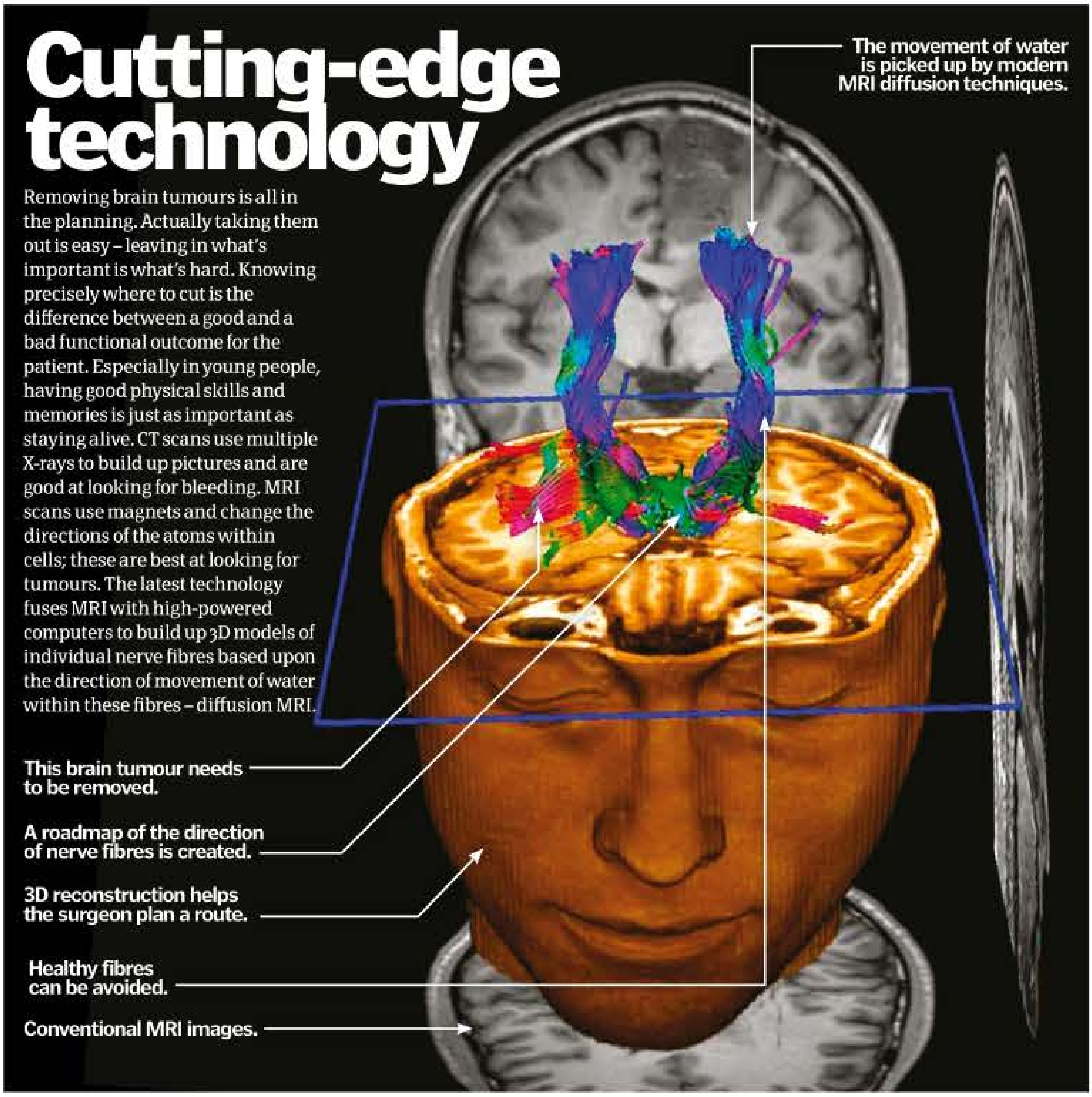
New neuronavigation techniques and robotic surgery can help surgeons get to the hard-to-access places, which previously would have been inaccessible. Special scanning cameras and computers are used during the operation and are matched to a pre-existing scan to guide the surgeon's hand – much like the satellite navigation systems used by drivers. Neuroendoscopy, which involves the use of tiny cameras to access the brain, is opening up many new opportunities in brain surgery. Incredibly, it's possible to access the brain via a tiny cut in the back of the nose.

The brain is the network hub of the human body, co-ordinating all of the sensations we feel and then providing instructions for the complex movements we perform. Although it receives all of the pain signals from the body, the brain itself doesn't have pain receptors. This means that there is potential for neurosurgery to be carried out with the patient awake. However, there are pain receptors located in the skin, muscles and linings that surround the brain, so it certainly isn't for everyone and it isn't performed everywhere.

Incredibly, there are bits of your brain that you can survive without – and you might not even notice any difference. It really depends on which part of the brain is removed – remove even a small part of the brainstem, for example, and you'll die instantly. However, removing or cutting larger parts of the main brain can leave just a few effects, such as memory problems. However, these discoveries were often made at the peril of surgeons operating and experimenting on patients in years gone by, which are now lessons confined to the history books.

Insertion of an electrode during surgery for Parkinson's disease

© Thomasbg



Cutting-edge technology

Removing brain tumours is all in the planning. Actually taking them out is easy – leaving in what's important is what's hard. Knowing precisely where to cut is the difference between a good and a bad functional outcome for the patient. Especially in young people, having good physical skills and memories is just as important as staying alive. CT scans use multiple X-rays to build up pictures and are good at looking for bleeding. MRI scans use magnets and change the directions of the atoms within cells; these are best at looking for tumours. The latest technology fuses MRI with high-powered computers to build up 3D models of individual nerve fibres based upon the direction of movement of water within these fibres – diffusion MRI.

The movement of water is picked up by modern MRI diffusion techniques.
This brain tumour needs to be removed.
A roadmap of the direction of nerve fibres is created.
3D reconstruction helps the surgeon plan a route.
Healthy fibres can be avoided.
Conventional MRI images.

The right tools for the job...

Discover the equipment used by brain surgeons

© Marvin 101 2009

Guglielmi detachable coil

These platinum wires are fed into small aneurysms (enlarged arteries) within the brain via an artery in the groin. Once coiled up inside the aneurysm sac, they stop blood flow and thus prevent bleeding.

Surgical microclamps

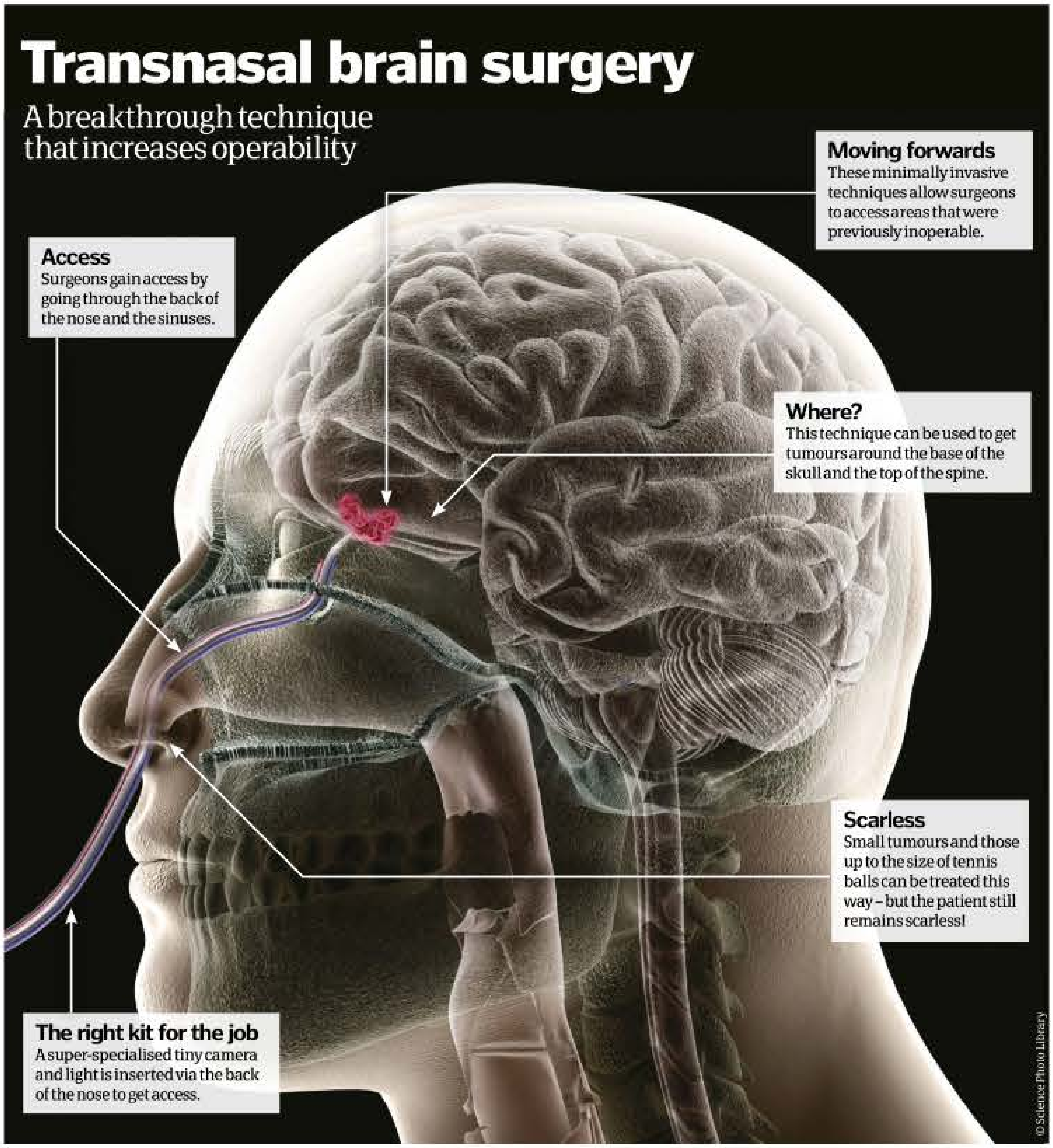
These small clamps can be used to grab tumours to help the surgeon dissect them away from surrounding structures.

High-performance microscope

These powerful microscopes with bright lights enable surgeons to operate through tiny incisions or keyholes, which prevents damage to those important surrounding structures.

Transnasal brain surgery

A breakthrough technique that increases operability



Moving forwards
These minimally invasive techniques allow surgeons to access areas that were previously inoperable.

Access
Surgeons gain access by going through the back of the nose and the sinuses.

Where?
This technique can be used to get tumours around the base of the skull and the top of the spine.

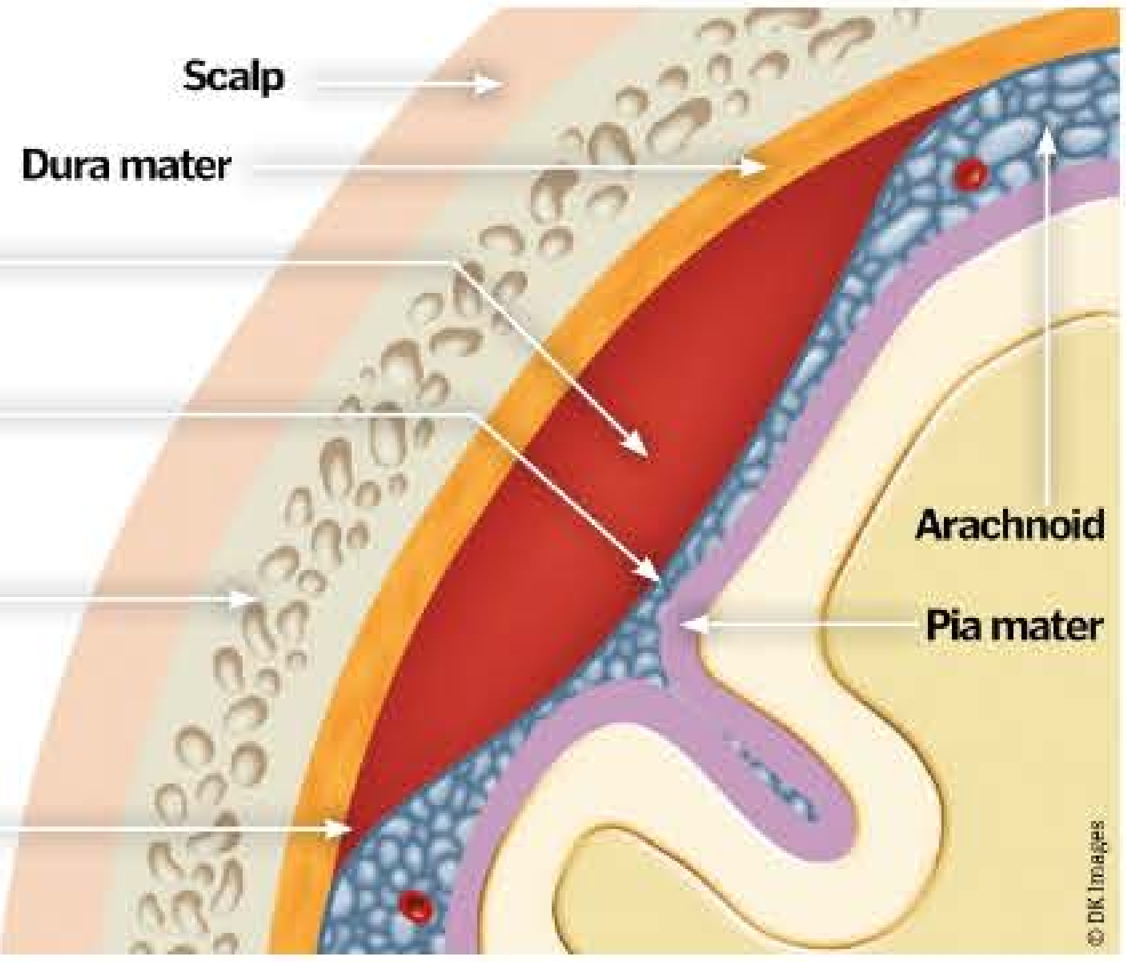
Scarless
Small tumours and those up to the size of tennis balls can be treated this way – but the patient still remains scarless!

The right kit for the job
A super-specialised tiny camera and light is inserted via the back of the nose to get access.

© Science Photo Library

Time-critical!

A haemorrhage needs urgent attention to save a life



Clot
A blood vessel has broken, forming a clot (haematoma).

Under pressure
The clot is causing increased pressure within the skull, squeezing the brain.

Skull
Since the skull is rigid, the brain is forced downwards towards the only exit – into the spinal column. This rapidly leads to death unless treated, as it damages the vital brainstem.

Life-saving
In true life-saving surgery, a surgeon will cut away a small piece of skull (craniotomy), clear away the clot and stop the bleeding.

© DK Images

The right tools for the job…

Discover the equipment used by brain surgeons

Navigation systems

This advanced computer system merges pre-operative CT and MRI scans with intra-operative information gathered from lasers and infrared. The result is a 'map', that surgeons can then follow in order to safely navigate to tumours located in hard-to-reach places.

Burr-hole drill

Although not used much any more in the Western world, a drill is used to evacuate blood clots that form around the brain following accidents. They are still used in some parts of the world.

Haemostat

A vital surgical tool, a haemostat is a scissor-shaped device used to control bleeding. They are locked in place via a series of interlocking teeth, which can be varied according to the amount of pressure needed.

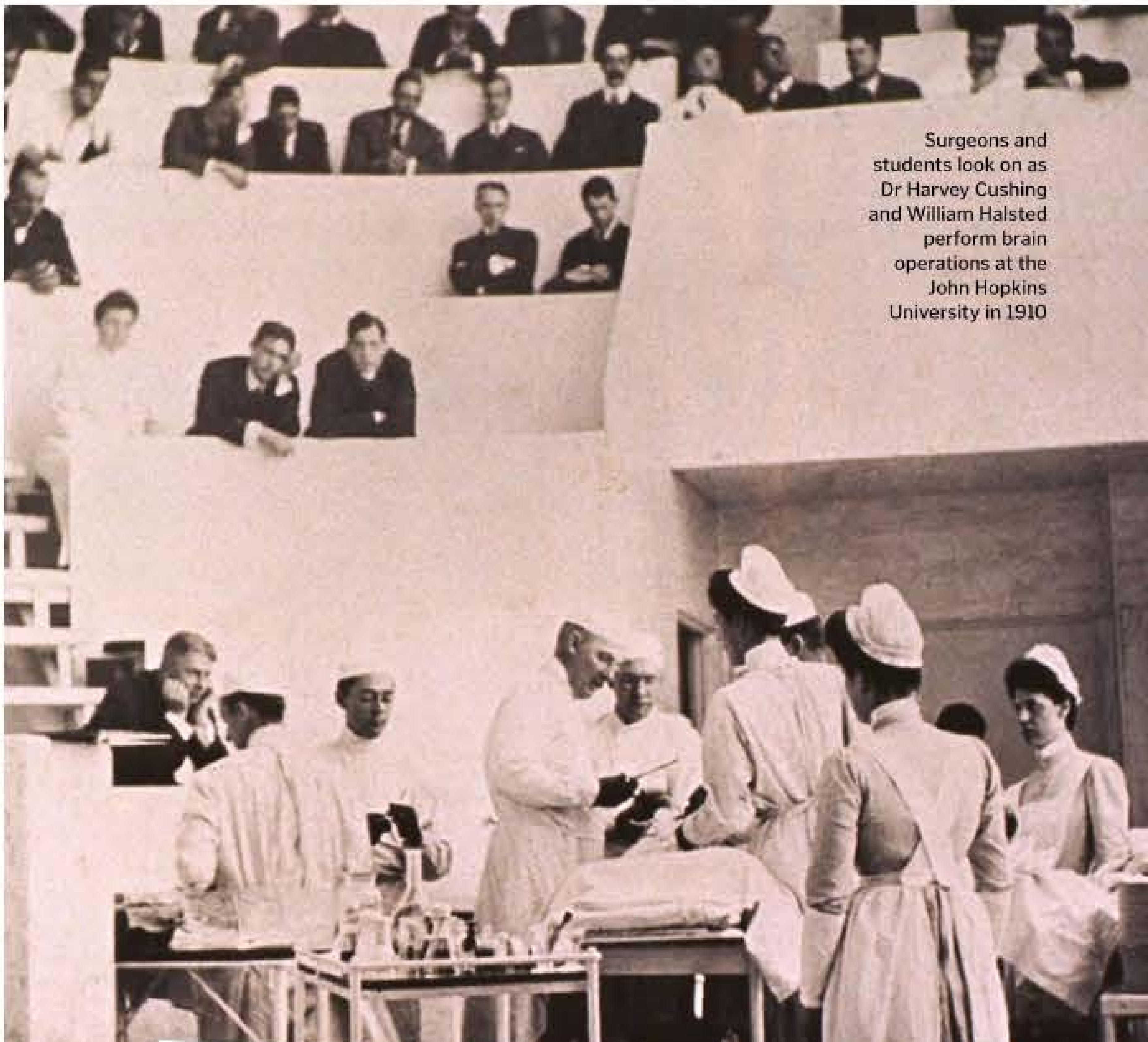
Harvey Cushing – neuroscience pioneer

As the father of modern-day neurological surgery, Harvey Cushing pioneered the medical profession, inspiring future generations to reap the rewards of his insightful studies and profound discoveries.

Born in Cleveland, Ohio, in 1869, he was the next generation in a long line of physicians, following his father, grandfather and great-grandfather. Inheriting a thirst for knowledge and aptitude for science, Cushing graduated from the prestigious Yale University in 1891. His first venture in the world of medicine began while studying at Harvard Medical School, completing his degree four years later.

To this day seen as the hub for surgical excellence, Cushing moved to Baltimore to train at Johns Hopkins Hospital as a surgeon. Under the watchful eye of William S Halsted, a surgical pioneer in his own right, he flourished, taking particular interest in the human body's nervous system and the growing specialisation of neurology. During the early 1900s, Cushing would publish several academic papers on the subject, even defining its scope in one entitled *The Special Field of Neurological Surgery.*

At the time of his rise to surgical success, traditional practises to explore the brain and perform extraction of cranial tumours were rudimentary, to say the least. With most surgeons opting to break apart a large amount of the skull to gain entry to the brain, Cushing instead developed a method to resect a small piece of bone from the skull and carefully manoeuvre through the grey matter to a tumour's location. This restricted approach was then advanced by the revolutionary new technique of X-ray imaging. As the first ever surgeon to image a brain tumour, Cushing had paved the way for tumour diagnosis without surgical intervention.



Surgeons and students look on as Dr Harvey Cushing and William Halsted perform brain operations at the John Hopkins University in 1910

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Designed by Cushing, the Cushing/Whitney Medical Library was built in 1940 at the heart of Yale Medical School

Genius in progress

Cushing's journey to define neurosurgery and further our knowledge of the brain

1869 Born on 8 April to Bessie Williams and Kirke Cushing, Harvey Cushing was the youngest of ten children.

1891 Cushing graduates from Yale University in Connecticut, US, with a bachelor's degree.

1985 Beginning his career in medicine, Cushing graduates from Harvard Medical School.

1896 He moves to Johns Hopkins Hospital to train as a surgeon under the respected William S Halsted.

1902 Cushing defines the body's response to intracranial pressure caused by injury to the brain.

Behind the man

Uncover the truth about the extraordinary surgeon

© Getty

He was a workaholic

Between 1918 and 1928 Cushing published six books alongside almost 100 scientific papers and reports. In order to achieve this, it's estimated that he wrote more than 10,000 words per day.

He was also a war doctor

During World War I, Cushing travelled to France and spent over three months treating around 133 soldiers with brain injuries.

He was an award-winning writer

In 1926, Cushing won the prestigious literary Pulitzer Prize for the biography of Sir William Osler, a Canadian physician and one of the founding fathers of Johns Hopkins Hospital.

He only had nine toes

Suffering from Buerger's disease, a blood clotting condition had left one of Cushing's toes gangrenous. In 1935, he had the middle toe on his left foot amputated.

He was connected with the White House

Cushing's daughter Betsy became the first wife of James Roosevelt, son of America's 32nd president, Franklin D Roosevelt, in 1930.

The big idea

First described in a paper in 1912 entitled *The Pituitary Body and its Disorders*, Cushing outlined the science behind what would later be known as Cushing's disease. Becoming a common acquiesce with the human pituitary gland, Cushing uncovered its effect on the debilitating condition. Displaying symptoms of excess inflammation, Cushing's disease is the result of the pituitary gland's overproduction of adrenocorticotropic hormone (ACTH). In turn, this hormone triggers the release of another steroid hormone called cortisol. At normal levels, cortisol controls blood sugar levels and metabolism, for example, but during overproduction it can be damaging to the body. Cushing discovered that a tumour growing on the pituitary gland can expedite the production of cortisol in the body, deploying more ACTH, which can lead to damaging effects.

© Science Photo Library

Today, brain tumours can be seen thanks to MRI, but Cushing had to rely on X-rays

This was not Cushing's only accomplishment – during a career spanning more than 40 years, his work on the human brain excelled as he worked to develop surgical techniques, improve diagnosis and make numerous discoveries. His array of achievements bare his name, including the discovery of Cushing's disease and the Cushing reflex, defined as the body's physiological response to intracranial pressure.

However, Cushing continually took notice of one part of the brain, the pituitary gland, and particularly the tumours that could grow around it. As a focal point in his continued research, he stored samples of resected pituitary tumours in formaldehyde-filled jars for future reference. As time progressed, a whole collection of bottled brains and detailed patient notes began to form, but when one of his specimens was 'lost', Cushing decided to formally catalogue them all. Now known as the Cushing Brain Tumour Registry, over 2,200 case studies were recorded between the late 1800s and 1936, documenting the history and journey of neurological medicine from its infancy.

© Alamy

During his lifetime Cushing performed over 2,000 brain surgeries

Retiring from surgical service in 1932, a year later Cushing began a new role as Sterling Professor of Medicine in Neurology at Yale University. Imparting his wisdom onto the next generation of neurosurgeons, Cushing spent the last six years of his life teaching before passing away from a heart attack.

1912 **Having identified the connection between the pituitary gland and cortisol production, Cushing's disease is discovered.**

1913 **Cushing begins his role of Chief of Surgery at the Peter Bent Brigham Hospital.**

1931 **Reaching a medical milestone, Cushing completes his 2,000th verified tumour operation.**

1932 **Cushing retires as chief of surgery at the Peter Bent Brigham Hospital.**

1939 **After suffering a heart attack, Cushing dies on 7 October 1939, aged 70.**

How brains can control prostheses

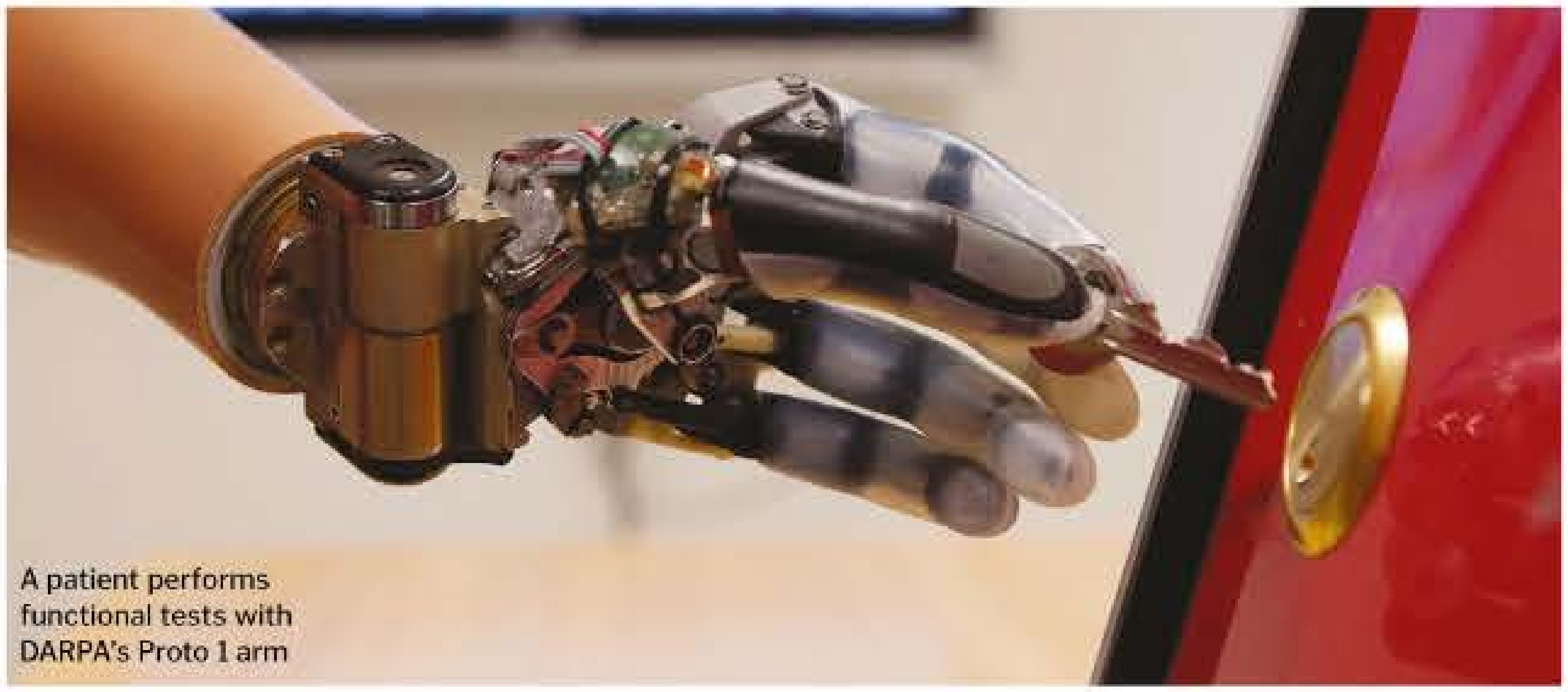
Learn how scientists are using the mind to manipulate life-changing technology

Scientists are exploiting ways to connect the human brain to modern prostheses (such as artificial limbs) or via computers to expand our functionality. It's hoped patients will be the ones to benefit, particularly those who have lost limbs.

Motor prostheses interpret the natural signals sent from the brain. The electrical signals sent are detected using microelectrodes, which can be implanted underneath the skin or even buried into nerves. The brain signals for each particular movement are unique and slightly different, and the aim is to detect these individually to allow patients the ability to perform fine movements. However, the science is still developing to more accurately recognise these signals, and the perfect prosthesis does not yet exist.

The initial technology was developed with monkeys and has come a long way since. There has been a massive push in this technology in recent years, with military funding starting to finance research to improve injured soldiers' quality of life. The initial crude devices are now being replaced with technologically cutting-edge equipment. The most modern devices use hundreds of sensors to determine the precise movements the brain is commanding and transmits them to some of the most complex and sophisticated prostheses ever.

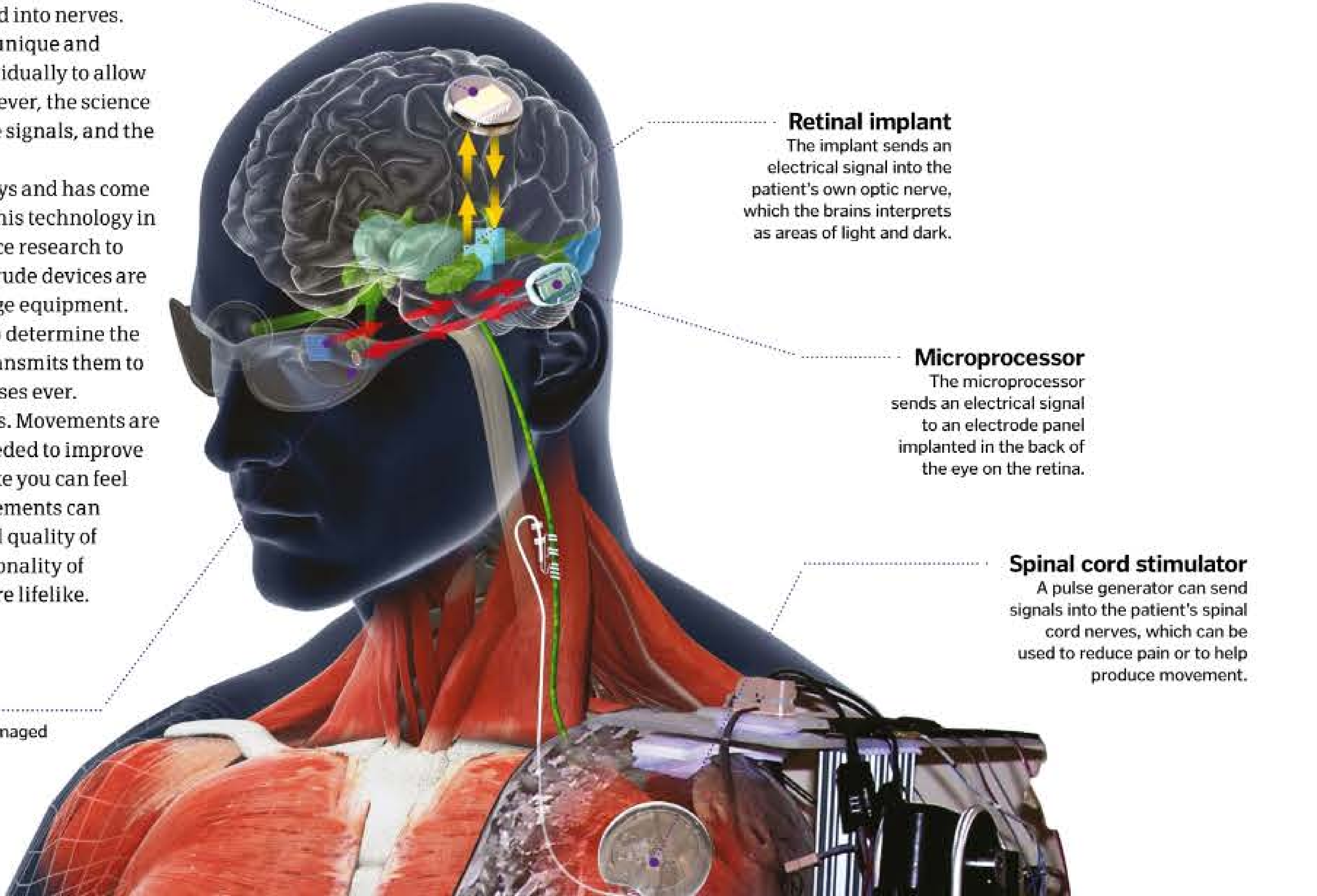
That said, this technology is still a work in progress. Movements are still limited and require refinement. Work is also needed to improve feedback to the patient from the prosthesis (much like you can feel what you're touching with your fingers), so that movements can become even more realistic. As both the lifespan and quality of the microprocessors improve, the motion and functionality of prostheses will become ever-more lifelike.



A patient performs functional tests with DARPA's Proto 1 arm

Where modern prostheses can make a difference

The latest prostheses are a combination of biology, technology and state-of-the-art design



Brain signals
Microprocessors to control movement of the limbs can be implanted near the brain to detect early signals.

Retinal implant
The implant sends an electrical signal into the patient's own optic nerve, which the brains interprets as areas of light and dark.

Microprocessor
The microprocessor sends an electrical signal to an electrode panel implanted in the back of the eye on the retina.

Spinal cord stimulator
A pulse generator can send signals into the patient's spinal cord nerves, which can be used to reduce pain or to help produce movement.

Bionic eye
For patients who have a damaged retina, a camera in a pair of glasses sends an image to the microprocessor.

Modern bioprostheses
These are combinations of modern computing and engineering technology that produce a lightweight yet realistically functional movements as possible.

Fine movements
Developing fine movements of the fingers is one of the ultimate aims of this field, as it will allow patients to write, feed themselves and perform other everyday tasks we take for granted.

Myoelectric prostheses

This cutting-edge prosthesis combines the best possible function with a pleasing aesthetic finish. Rather than using cables and pulleys like older prostheses, this uses batteries and microprocessors to interpret the brain's electrical activity. The main disadvantages are its current weight and expense, although both are coming down rapidly.

This myoelectric-driven grip prosthesis, known as the Michelangelo Hand, is made by Ottobock

History of prostheses

A look at some of the most game-changing developments in the world of prostheses

1957
First cochlear implant
The first cochlear implant converts sound waves into strong electrical impulses. They still bring improved hearing to many people around the globe today.

1990s
CAT-CAM
The widespread introduction of the modern fitting limb prosthesis – the contoured adducted trochanteric-controlled alignment method (CAT-CAM) – paves the way for the development of today's sophisticated prostheses.

2002
Median nerve cybernetics
A microelectrode array is implanted into a healthy volunteer's median nerve located in the arm, which enables him to control hand functions.

2008
Monkeys
Two monkeys learn to feed themselves marshmallows using a robotic arm controlled by a computer that's linked to their brains.

2009
Modular prosthetic limb
Developed by the US's Defense Advanced Research Projects Agency (DARPA), this prosthesis offers 22 degrees of motion with independent movement of each finger. The Proto prosthesis is still being developed to this day.

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TRICKS OF THE MIND

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Your brain is about to be tricked

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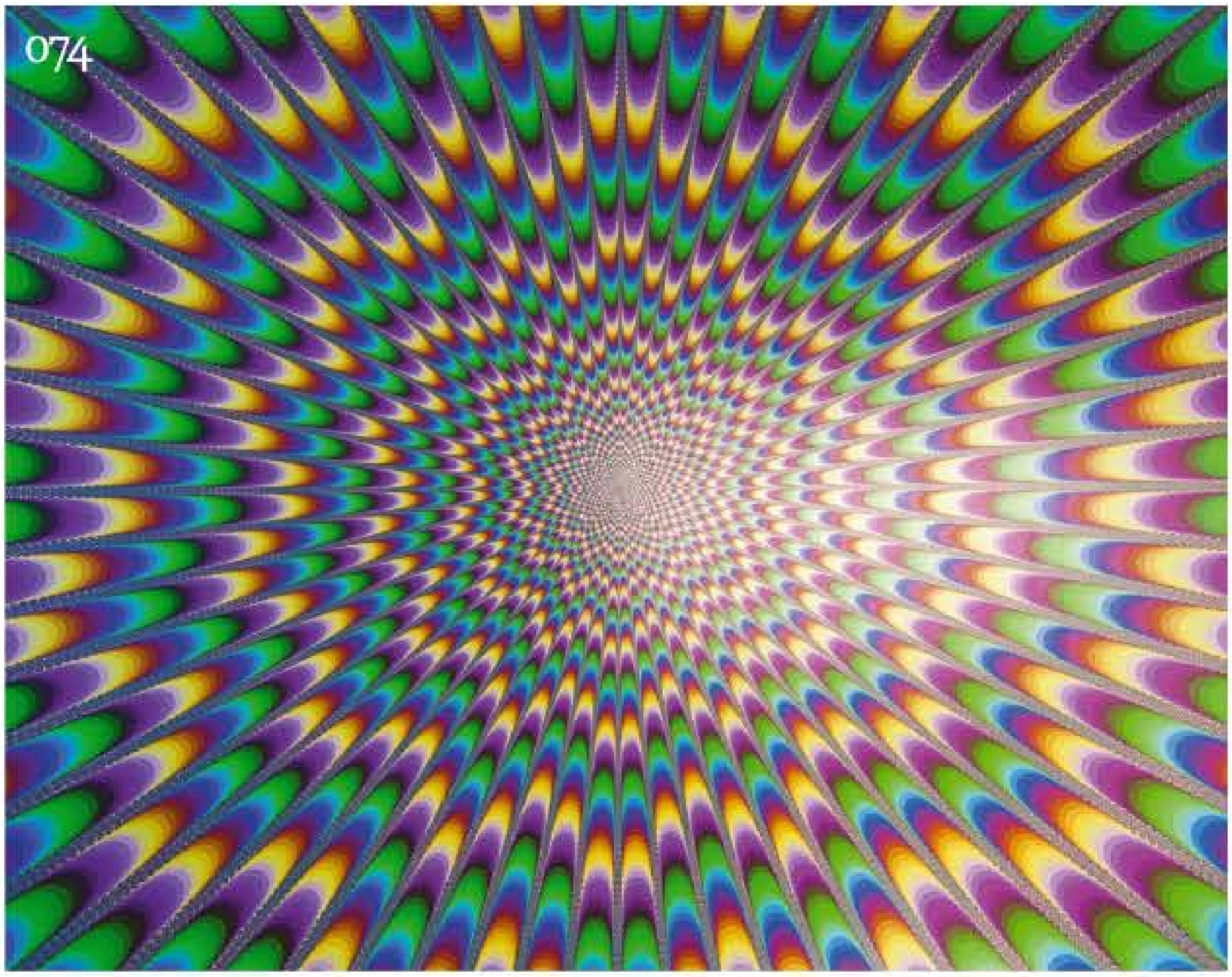
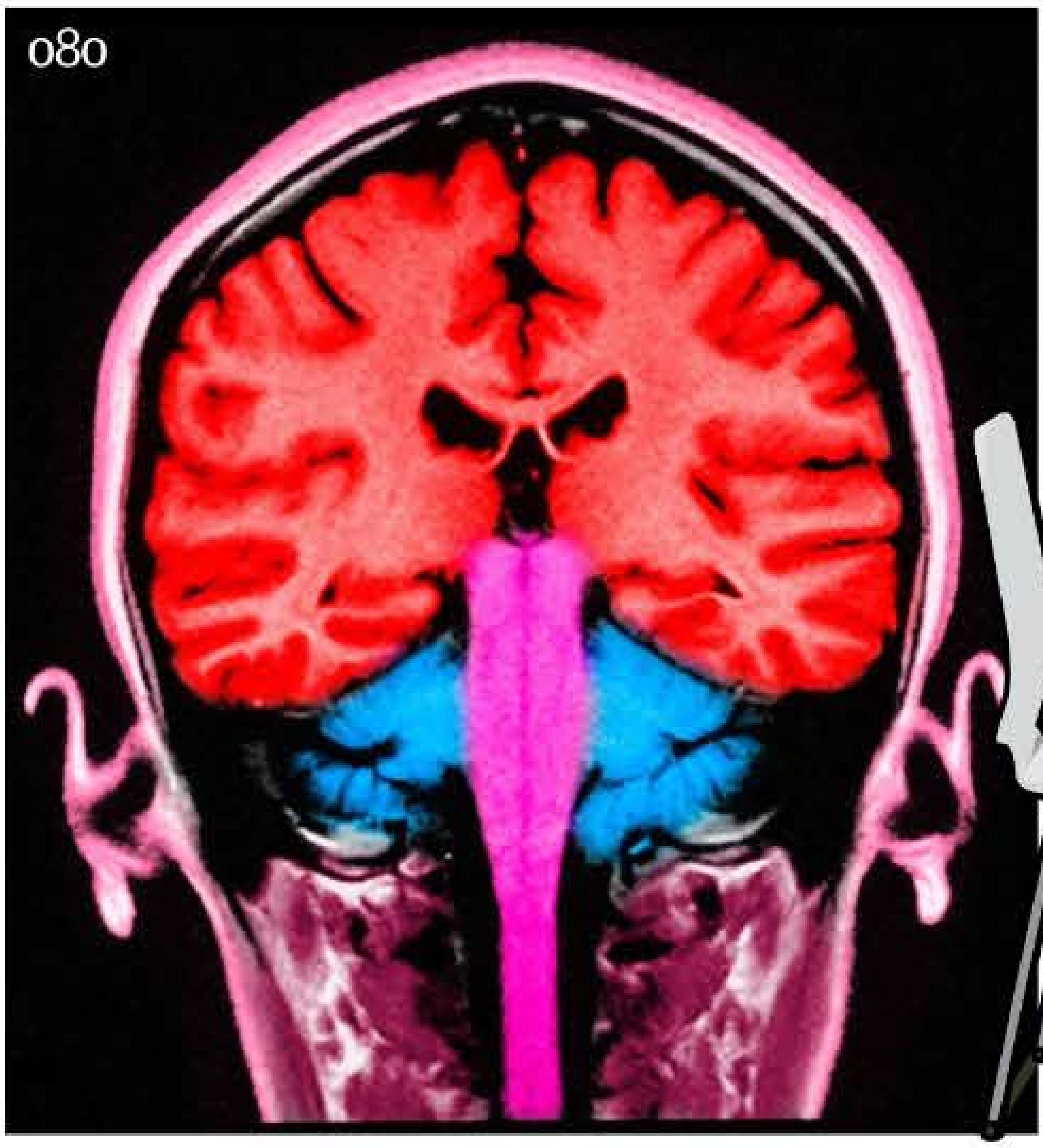
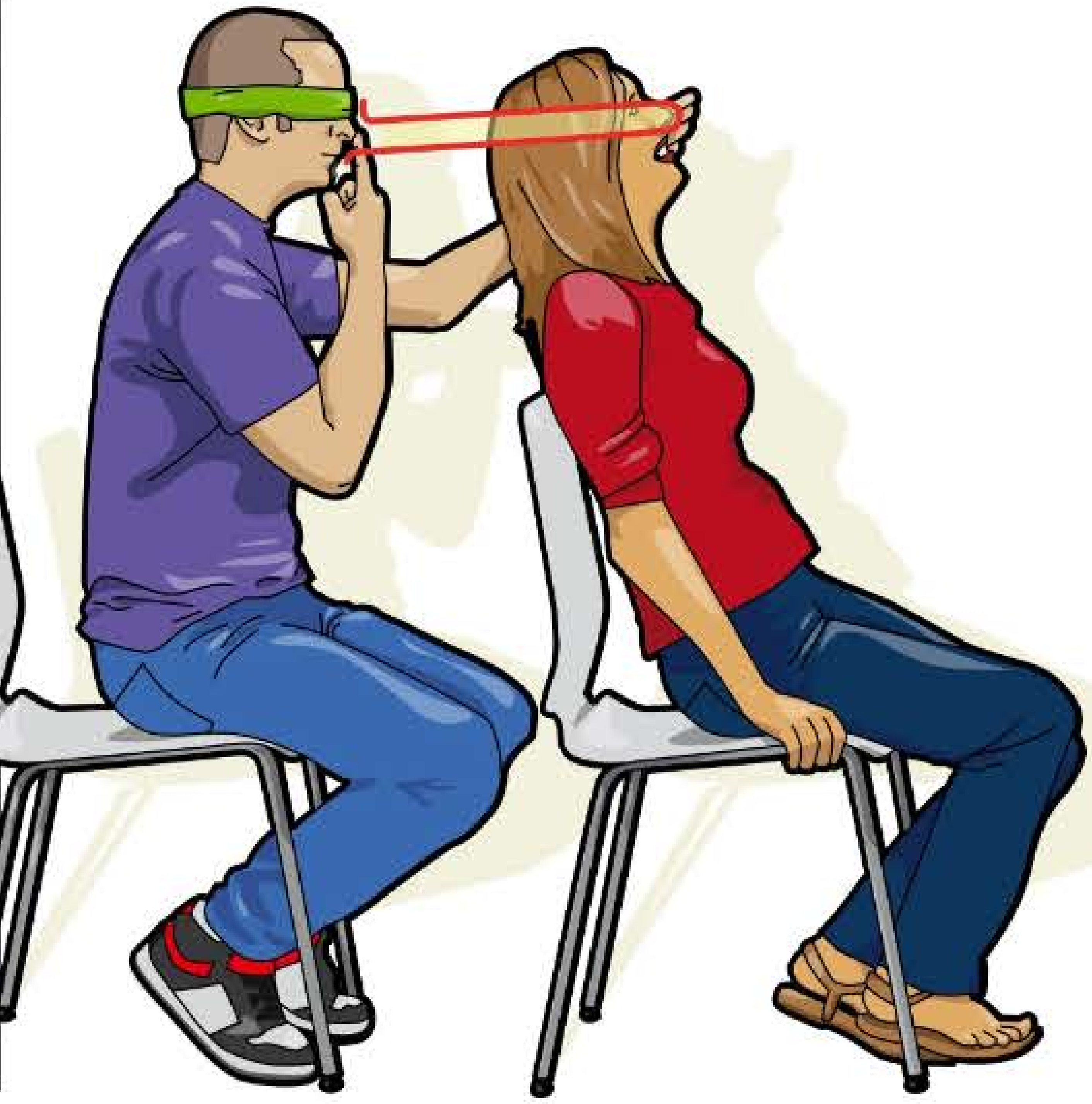
How do pretend drugs make us think we are better?

088 **Cognitive biases**
The evolutionary falsehoods that we all believe in







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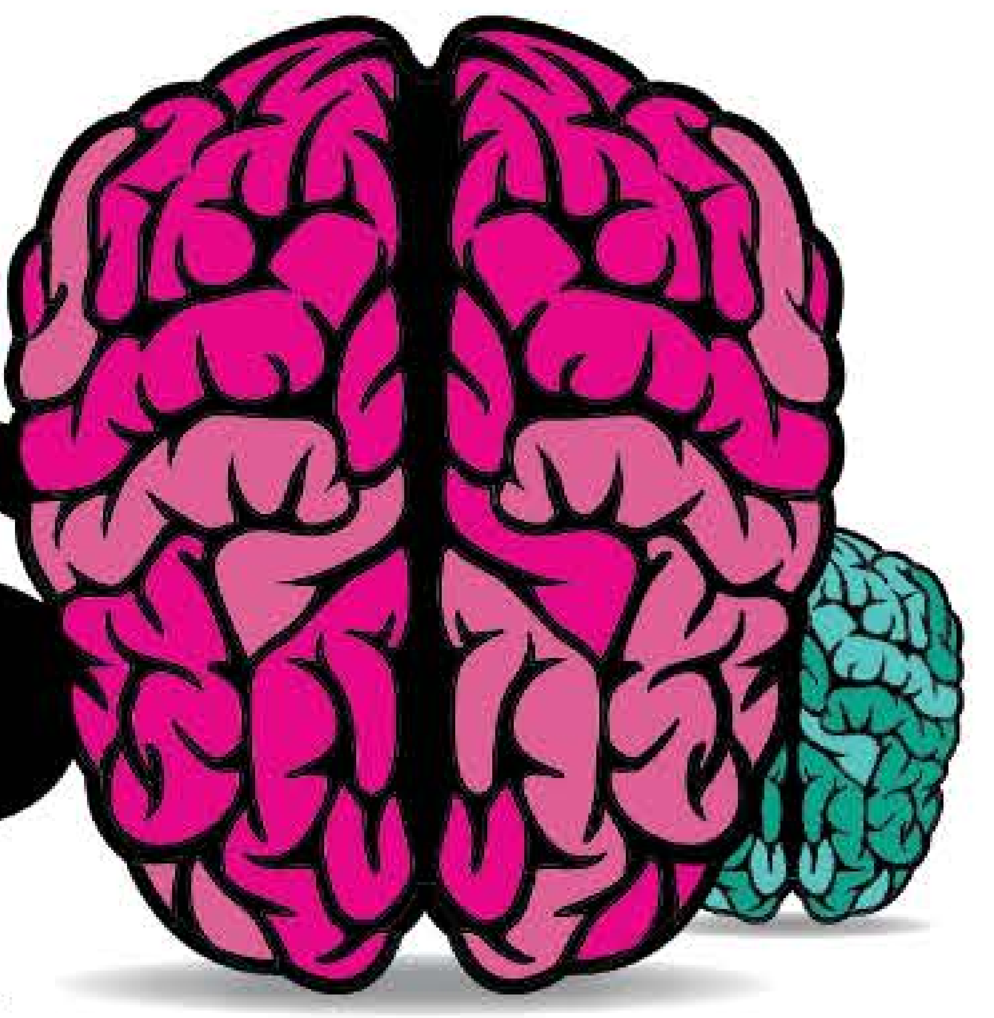
MIND TRICKS



Discover the mind-bending illusions that prove you shouldn't always believe what you see or feel

As you go about your daily life, your brain continuously perceives the world around you with the help of your senses. The constant stream of information it receives is overwhelming, so it regularly takes shortcuts to simplify what you see or feel and chooses the most likely interpretations. This helps it to concentrate on what's important, rather than focusing on everything at once. The brain is also very good at predicting the future, helping it to compensate for the slight delay between you physically seeing or touching something and receiving and processing those signals from your eyes or limbs. However, these shortcuts and predictions also make it possible for your brain to be fooled.

Humans have been discovering ways to trick the mind for millennia, with examples of optical illusions found in Stone Age cave paintings. Ancient Greek philosopher Aristotle noted that "our senses can be trusted but they can be easily fooled" with an illusion now referred to as the waterfall effect. While watching a waterfall he noticed that shifting his gaze from the moving water to the static rocks made the rocks appear to move in the opposite direction to the flow of water. Now known as 'motion aftereffect', it's caused by the wearing out of certain neurons in the brain as they perceive motion. When you move to look at the rocks, competing neurons overcompensate for those that are worn out, creating the illusion of movement.

Studying how the brain reacts to illusions has become much easier since Aristotle's day. Functional magnetic resonance imaging (fMRI) allows scientists to analyse the processes going on inside our heads as we experience certain images or situations, examining how the brain responds in real time. However, there is still a great deal more to be explored, as our responses to some illusions remain a mystery.

How we see

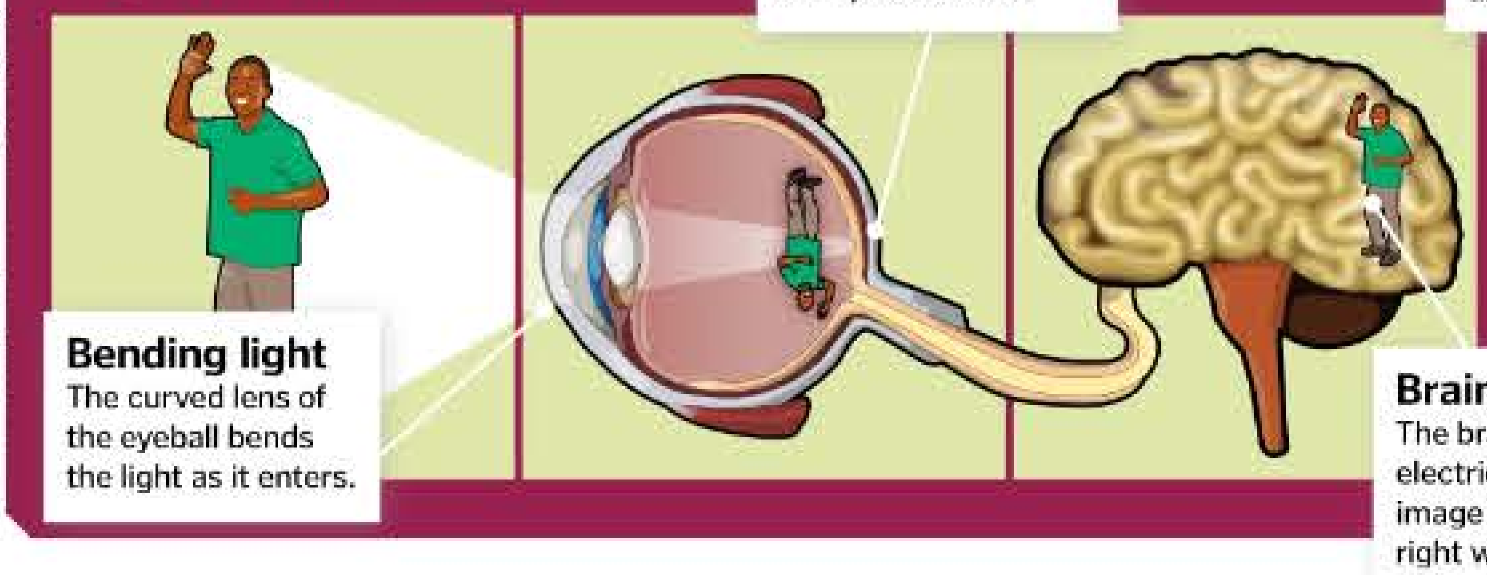
Your eyeballs are your window to the world, enabling your brain to create colourful three-dimensional moving images of your surroundings in amazing detail. They work a bit like a camera, allowing light to enter through a lens, which then focuses it onto a kind of sensor called the retina. Your eyes can even zoom like a camera, as muscles help to flatten the lens to see distant objects, or thicken it to see things close-up.

Once the light hits the retina, it is detected by light-sensitive cells called rods and cones. Rods are responsible for our sight in dark conditions, allowing us to see in monochrome, while cones allow us to see colour and detail in brighter conditions. When the light hits them, chemicals in the rods and cones change, creating an electrical signal that is sent to the brain.

Here the information from each eye is combined and compared so that an image of your surroundings can be accurately reconstructed with plenty of depth and contrast. This whole process takes about a hundredth of a second, enabling you to see the world almost in real time.

The human eye

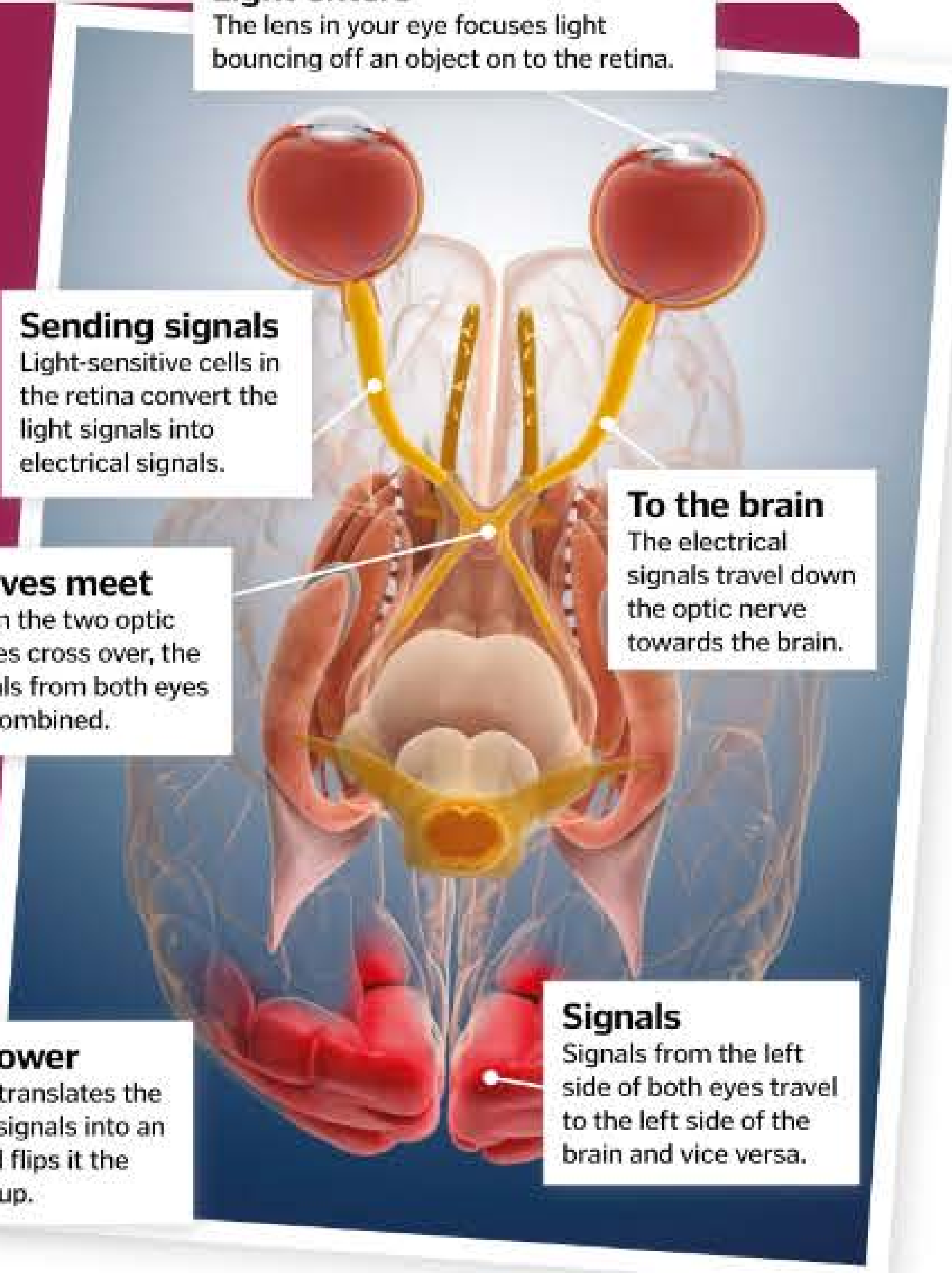
How do we turn waves of light into images of our surroundings?



Wrong way up
The light signals received by the retina are upside down.

Bending light
The curved lens of the eyeball bends the light as it enters.

Brain power
The brain translates the electrical signals into an image and flips it the right way up.



Light enters
The lens in your eye focuses light bouncing off an object on to the retina.

Sending signals
Light-sensitive cells in the retina convert the light signals into electrical signals.

Nerves meet
When the two optic nerves cross over, the signals from both eyes are combined.

To the brain
The electrical signals travel down the optic nerve towards the brain.

Signals
Signals from the left side of both eyes travel to the left side of the brain and vice versa.

© Thinkstock; Getty; WIKI; Illustration by Art Agency

> *"Humans have been discovering ways of tricking the mind for millennia"*

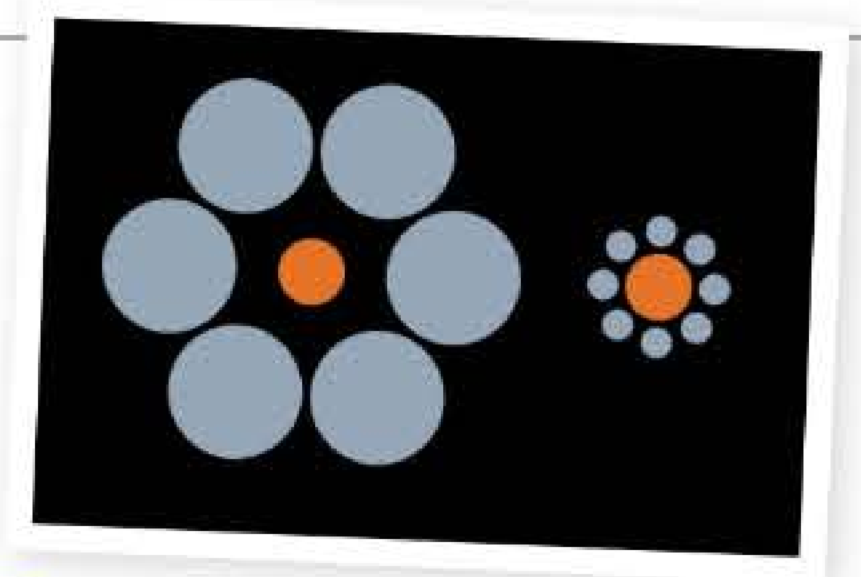
Size illusions

Discover how context can mask an object's true size

When you look at two objects next to each other, you are probably pretty confident in identifying whether they are the same size or if one is bigger than the other. However, there are certain optical illusions that prove you might not always get it right. That is because our brains often make judgements about the size of an object based on other objects that are nearby, and so can easily be fooled by context.

Take, for example, the Ebbinghaus illusion on the top right of this page. Many would consider the orange circle on the right to be larger than the one on the left, but they are in fact both exactly the same size. The brain uses the blue circles to judge the orange circles' size, and so because the blue circles on the left are larger, the left orange circle seems smaller in comparison.

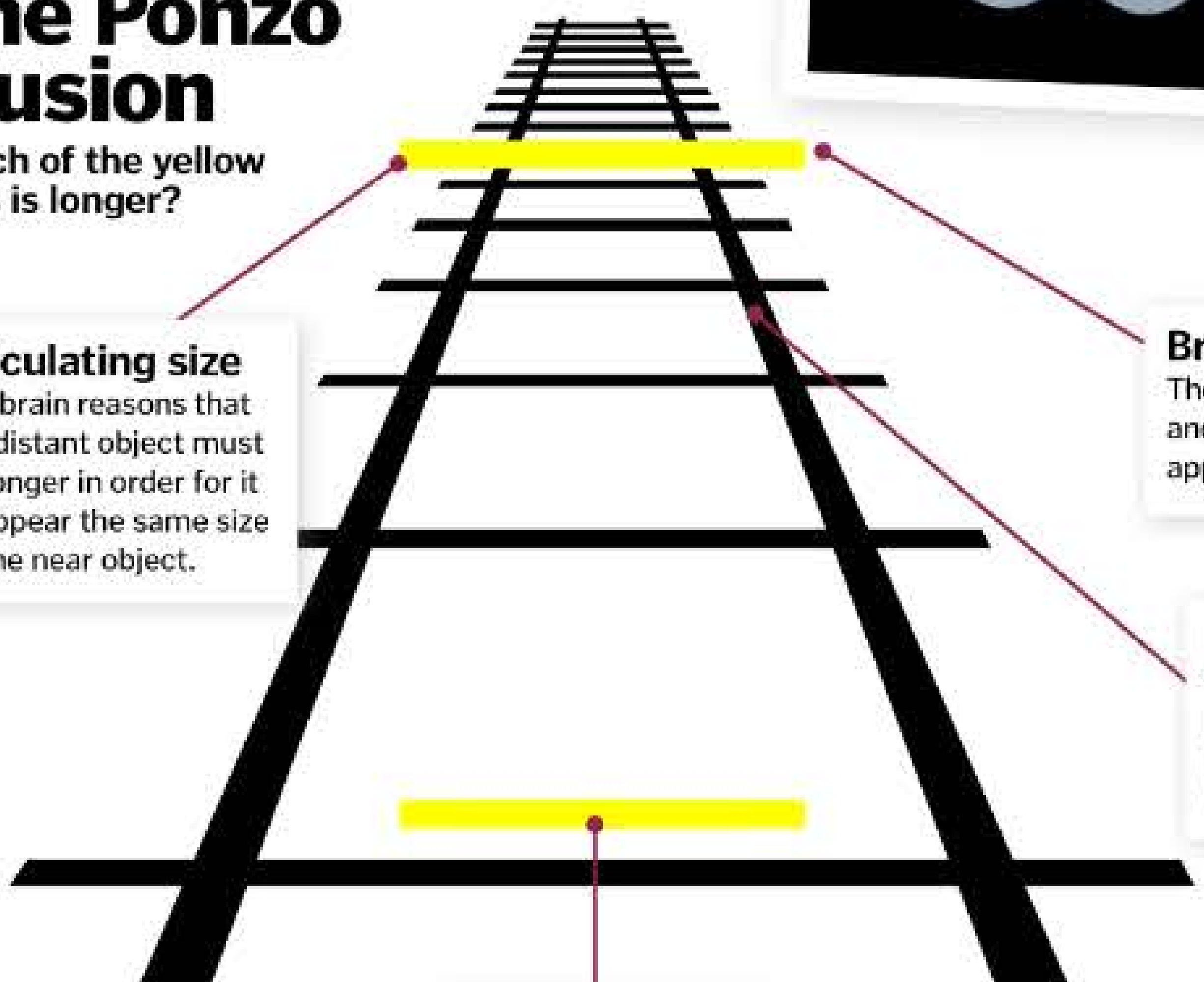
Context can also affect our brain's depth perception, making objects seem nearer or further away than they really are. This in turn can influence how we perceive their size, as illustrated by the Ponzo illusion shown here. It's this particular mind trick that makes the Moon appear bigger when it's near the horizon.



The Ebbinghaus illusion illustrates how context affects size perception

The Ponzo illusion

Which of the yellow lines is longer?



Calculating size
The brain reasons that the distant object must be longer in order for it to appear the same size as the near object.

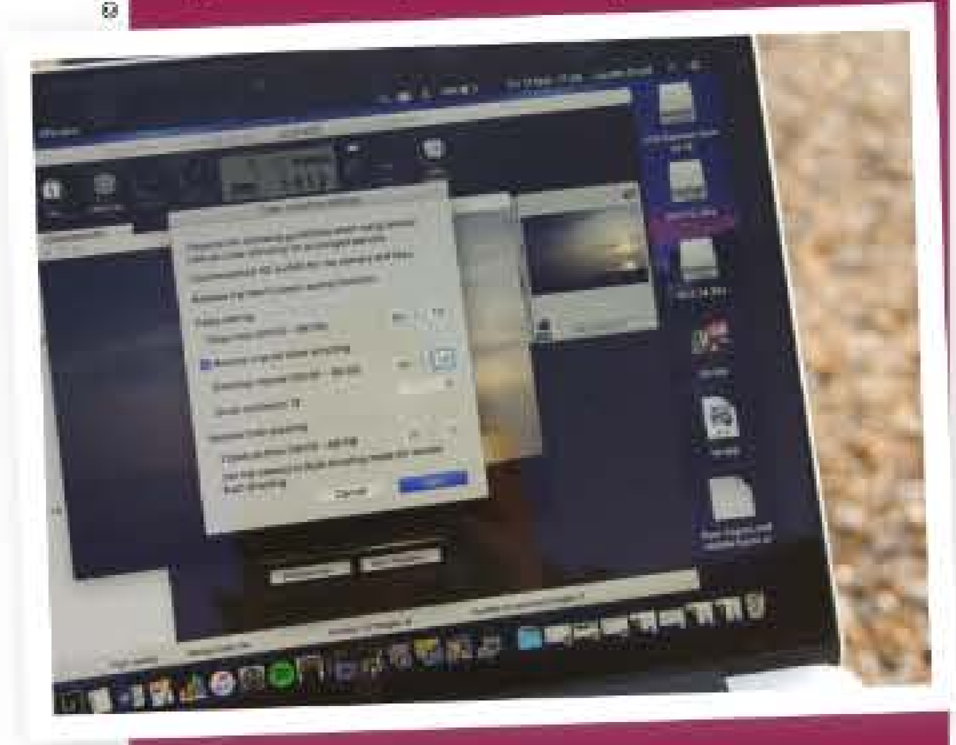
Brain fooled
The brain overcompensates and makes the top line appear longer.

In the distance
The converging parallel lines trick the brain into believing that the top line is further away.

In reality
The two yellow lines are actually both the same length.

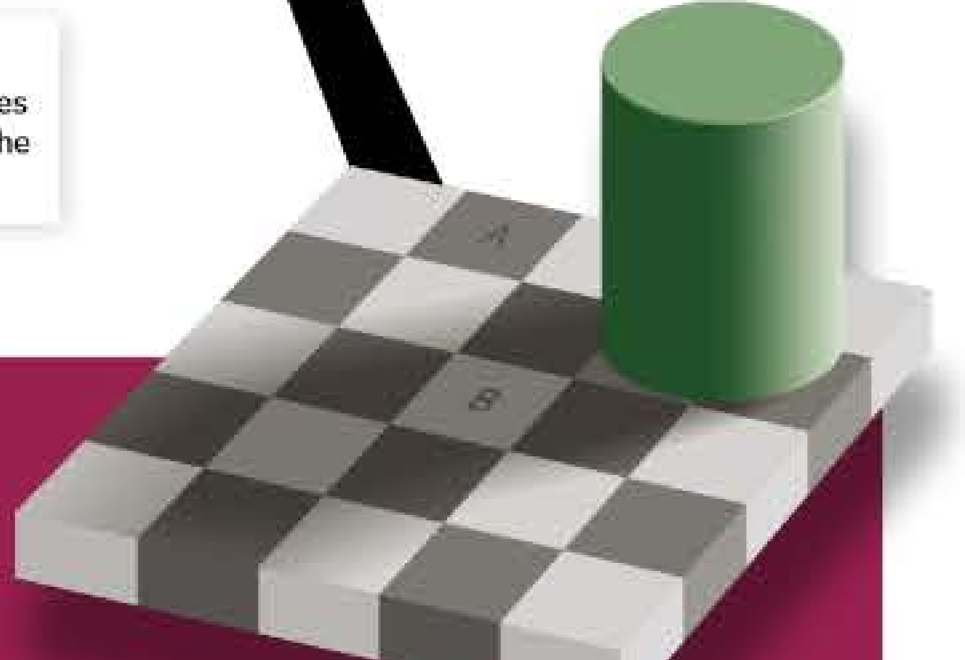
Screen flicker

If an LCD screen is filmed with a video camera, the screen often appears to flicker. This is because the screen is actually flickering in real life, and it's our eyes that are being fooled into seeing a continuous image. When a camera captures a scene, it takes a series of rapid shots and stitches them together to create a moving image. Therefore, if its frame rate does not match that of the screen it is filming, it picks up the flickering. Our eyes, on the other hand, are constantly sending information to our brains, and so hang onto an afterimage of the light from the screen in order to fill in the gaps caused by the flickering.



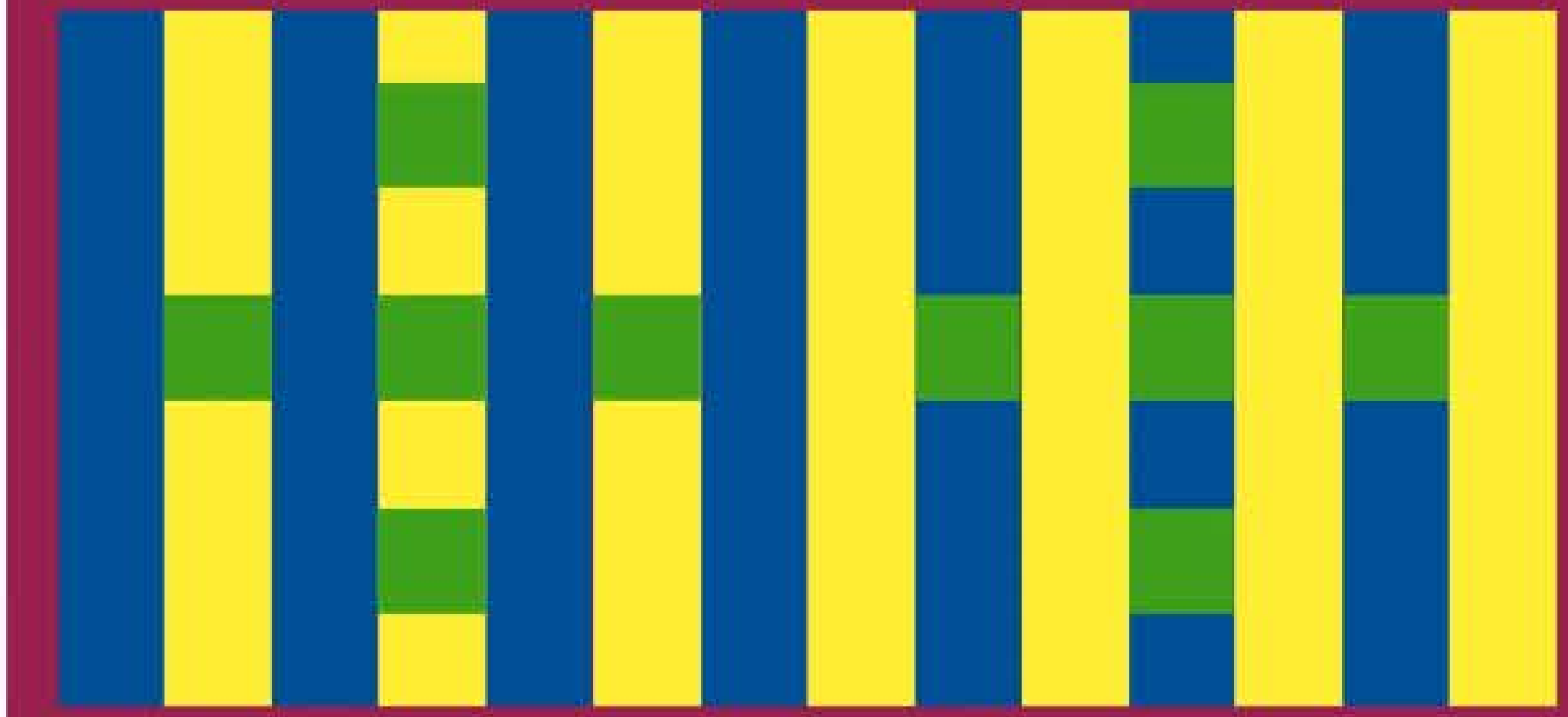
LCD screens rapidly switch their power on and off in order to regulate their brightness

Contrast illusions



In this contrast illusion, squares A and B are actually the same shade of grey

As well as altering how we perceive an object's size, context can also affect how we perceive its colour. In this image, all of the green squares are exactly the same shade, but the ones on the left appear darker than those on the right. This is because the green squares on the left are on a lighter background, creating more contrast and so making them appear darker in comparison to their surroundings. This simultaneous contrast illusion is believed to be caused by the way the retina's light-sensitive cells process two different colours next to each other. When the light reflected from a brighter background hits one of these cells, any adjacent cells are inhibited from firing off signals. This causes the light reflected from the green squares on the left to activate a stronger signal, making them appear darker.



The green squares on the yellow background appear darker than those on the blue background

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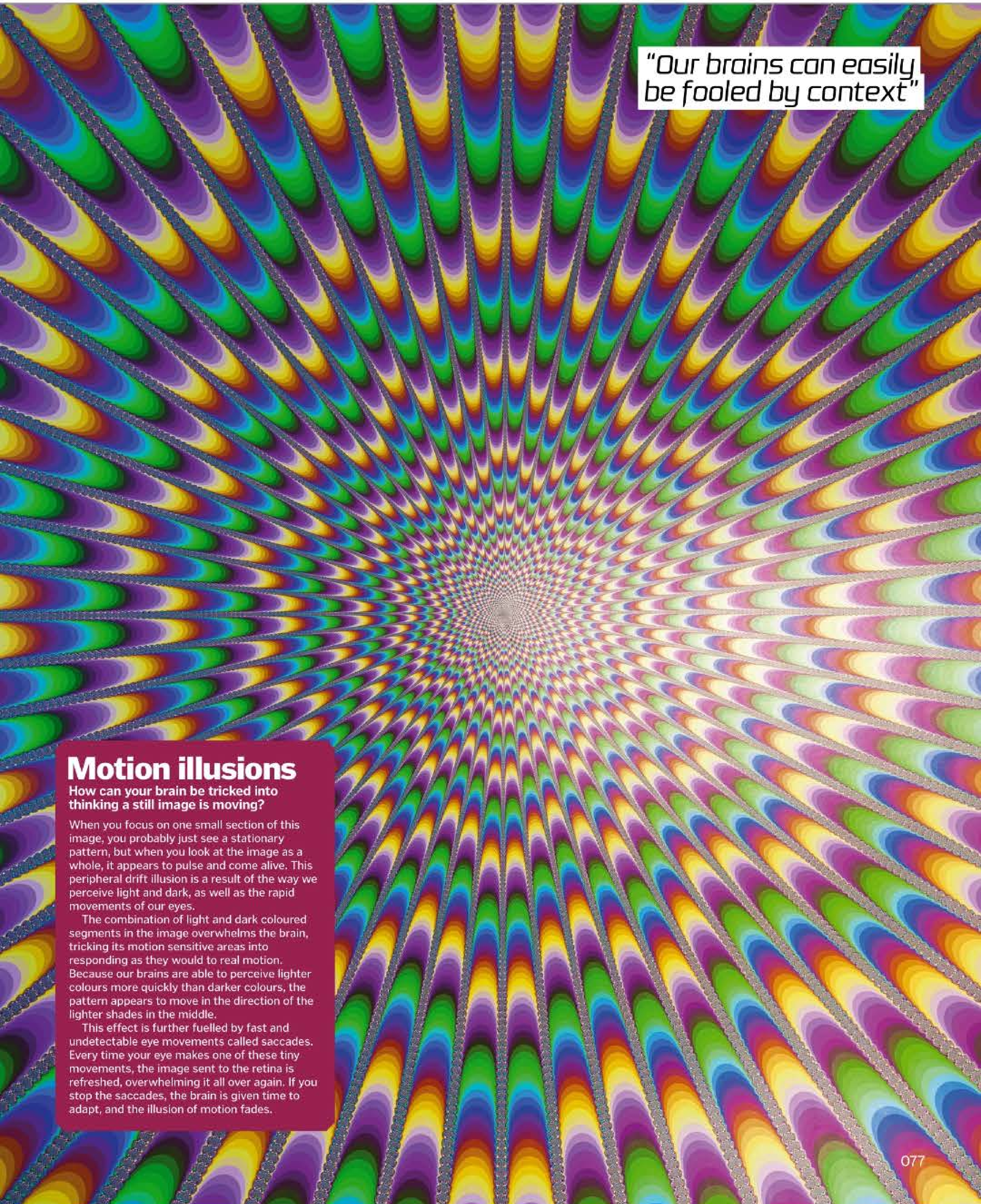


"Our brains can easily be fooled by context"

Motion illusions

How can your brain be tricked into thinking a still image is moving?

When you focus on one small section of this image, you probably just see a stationary pattern, but when you look at the image as a whole, it appears to pulse and come alive. This peripheral drift illusion is a result of the way we perceive light and dark, as well as the rapid movements of our eyes.

The combination of light and dark coloured segments in the image overwhelms the brain, tricking its motion sensitive areas into responding as they would to real motion. Because our brains are able to perceive lighter colours more quickly than darker colours, the pattern appears to move in the direction of the lighter shades in the middle.

This effect is further fuelled by fast and undetectable eye movements called saccades. Every time your eye makes one of these tiny movements, the image sent to the retina is refreshed, overwhelming it all over again. If you stop the saccades, the brain is given time to adapt, and the illusion of motion fades.

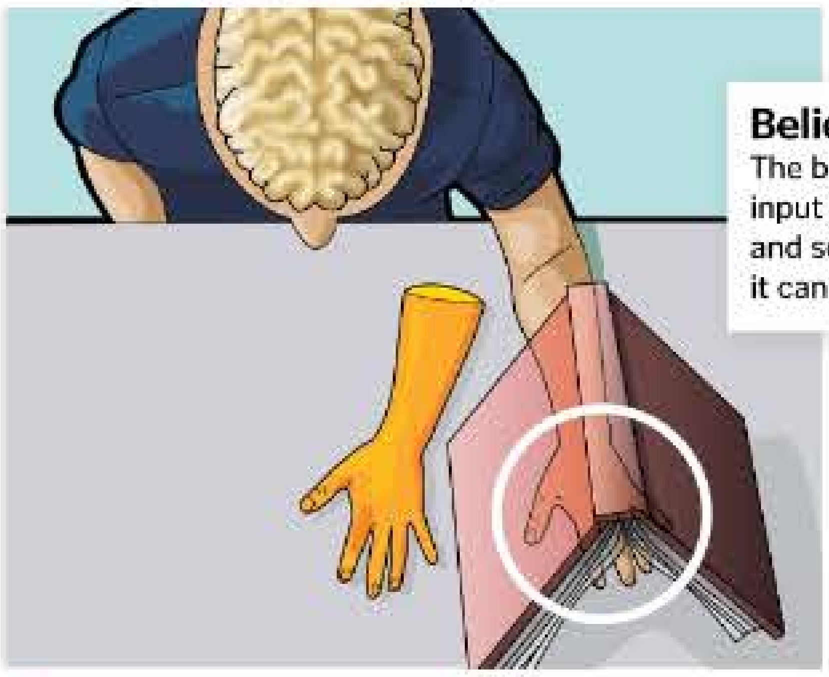
Tricking your body

Fooling your brain can help reduce physical pain and even create pain when there is none

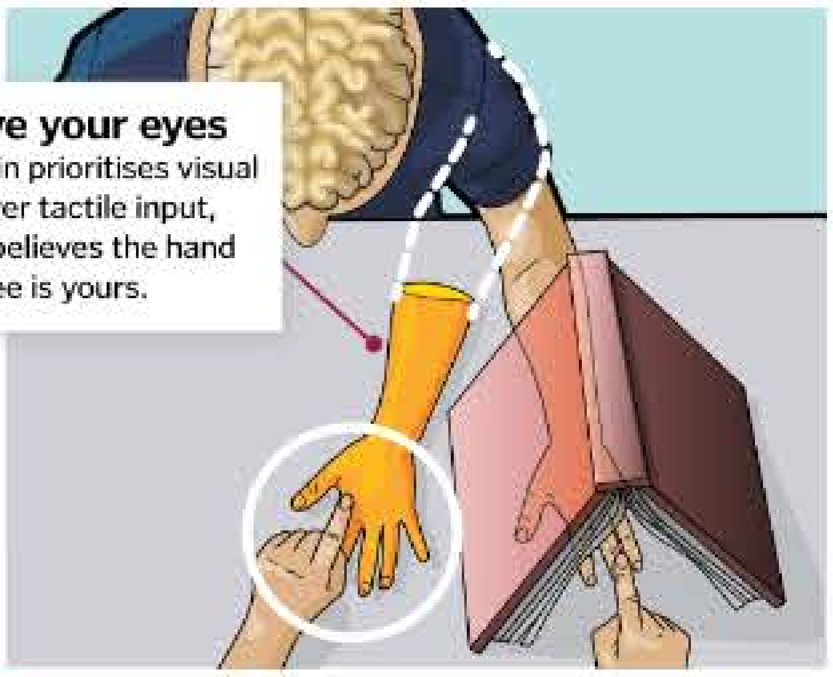
Horizontal lines on clothing affect how our eyes view people's body shape

Rubber hand illusion

Trick your mind into believing that a fake hand is your own

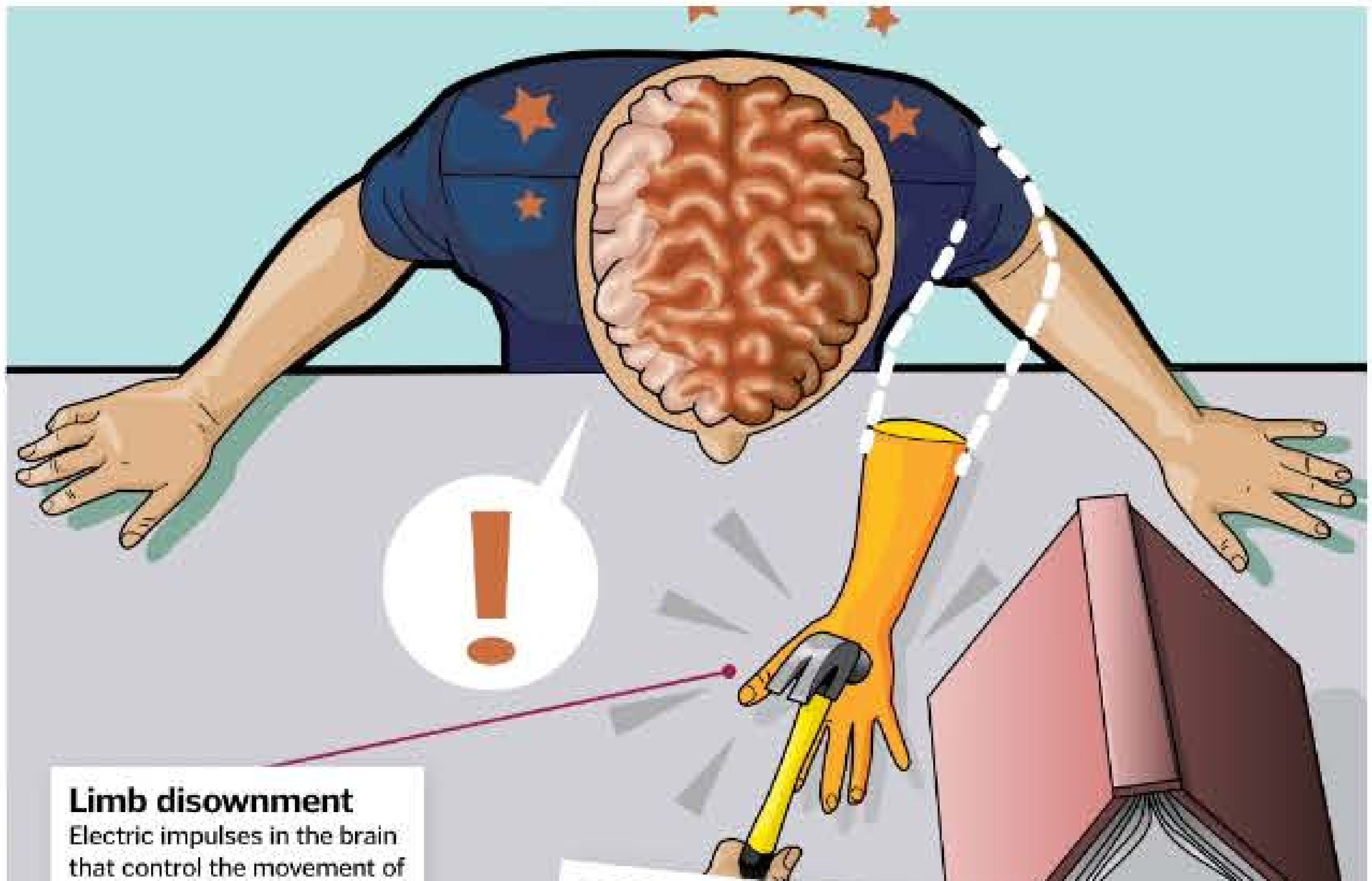


1 Hide your hand
Place an open book on the table in front of you, then sit with one hand underneath the book so that you cannot see it. Put the rubber hand in front of you so that it is lined up with your shoulder. Covering your arm and the 'arm' of the fake hand with a cloth will help the illusion.



Believe your eyes
The brain prioritises visual input over tactile input, and so believes the hand it can see is yours.

2 Start stroking
Get a friend to stroke the middle finger of your real hand and the middle finger of the fake hand at the same time. After one or two minutes you will start to feel like the fake hand is your own and that your real hand no longer exists.



Limb disownment
Electric impulses in the brain that control the movement of your hand weaken, making it feel like it is no longer there.

3 Inflict some pain
Get your friend to then hit the rubber hand with a hammer. You should feel a brief jolt of pain as your brain combines visual and physical information to create a feeling of ownership over the fake hand.

Body illusions can be used to help amputees alleviate phantom limb pain

Mirror therapy

The ability to fool the brain into experiencing ownership of a fake body part is proving useful for helping patients with phantom limb pain – the feeling of pain in an amputated or paralysed limb. By placing the affected limb behind a mirror and then moving the opposite, unaffected limb in front of the mirror, the brain can be tricked into thinking the reflection is a real moving body part. This enables the patient to mentally move their phantom limb, perhaps unclenching it from a painful position to provide relief. The illusion works because the brain prioritises visual feedback over tactile feedback and so the observation of movement still manages to stimulate the processes in the brain involved in real movement.

Mirror therapy tricks the brain into thinking a reflected limb is real

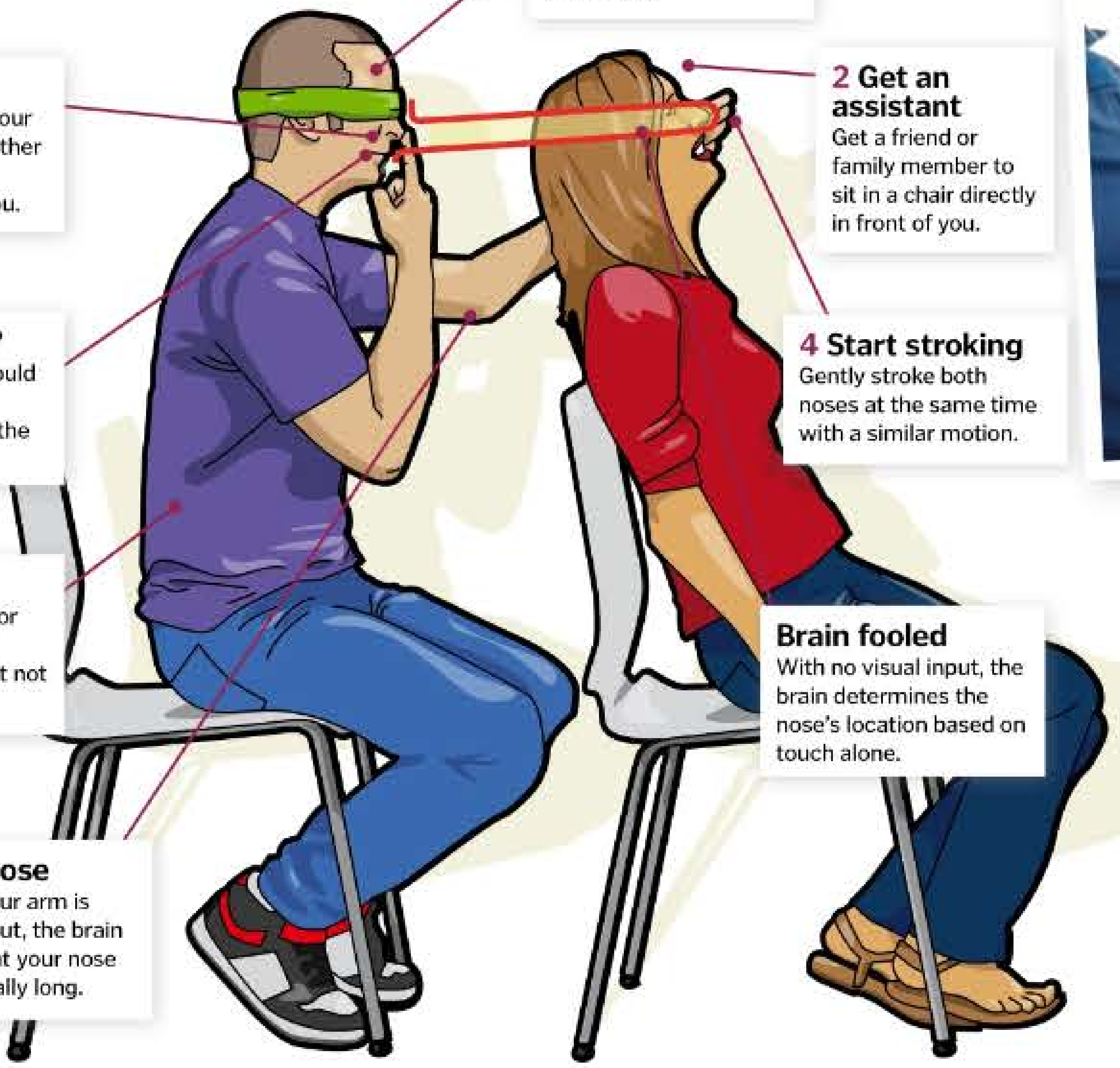
Shrinking pain

The brain's tendency to prioritise visual input over tactile input makes it possible to manipulate the experience of pain. In a study conducted by researchers at Oxford University, participants suffering from chronic pain in their right arm were asked to move the limb while looking at it through a pair of binoculars. They were then asked to do the same again, but while looking through the other end of the binoculars. When presented with a magnified view of their arm, every participant reported experiencing an increase in pain, but when their arm looked smaller or further away, the pain, and even the swelling, increased significantly less. Exactly how this illusion works remains unclear. One theory is that magnifying the arm enhances the sense of touch, while another suggests that by 'minifying' the limb, the brain's sense of ownership of it is reduced, thus desensitising it to the pain.

Binoculars have been proven to help reduce physical pain

The Pinocchio illusion

Experience the feeling of having an extremely long nose. It's no lie!



1 Wear a blindfold
Sit in a chair and cover your eyes with a blindfold so that you cannot see.

2 Get an assistant
Get a friend or family member to sit in a chair directly in front of you.

3 Hold noses
Place one hand on your own nose, and the other on the nose of the person in front of you.

4 Start stroking
Gently stroke both noses at the same time with a similar motion.

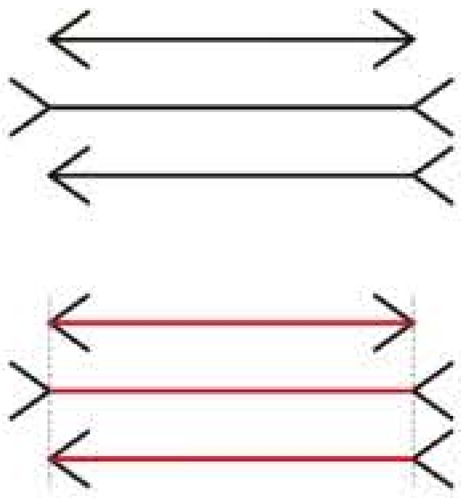
5 Which nose?
After a minute it should feel as though both hands are touching the same nose.

Success rate
This illusion works for over 50 per cent of people, so you might not feel any effect.

A long nose
Because your arm is stretched out, the brain reasons that your nose must be really long.

Brain fooled
With no visual input, the brain determines the nose's location based on touch alone.

The rubber hand illusion can fool our brains into 'adopting' an additional, artificial limb as our own



The Müller Lyer illusion features three arrows of the same length, but some appear longer than others

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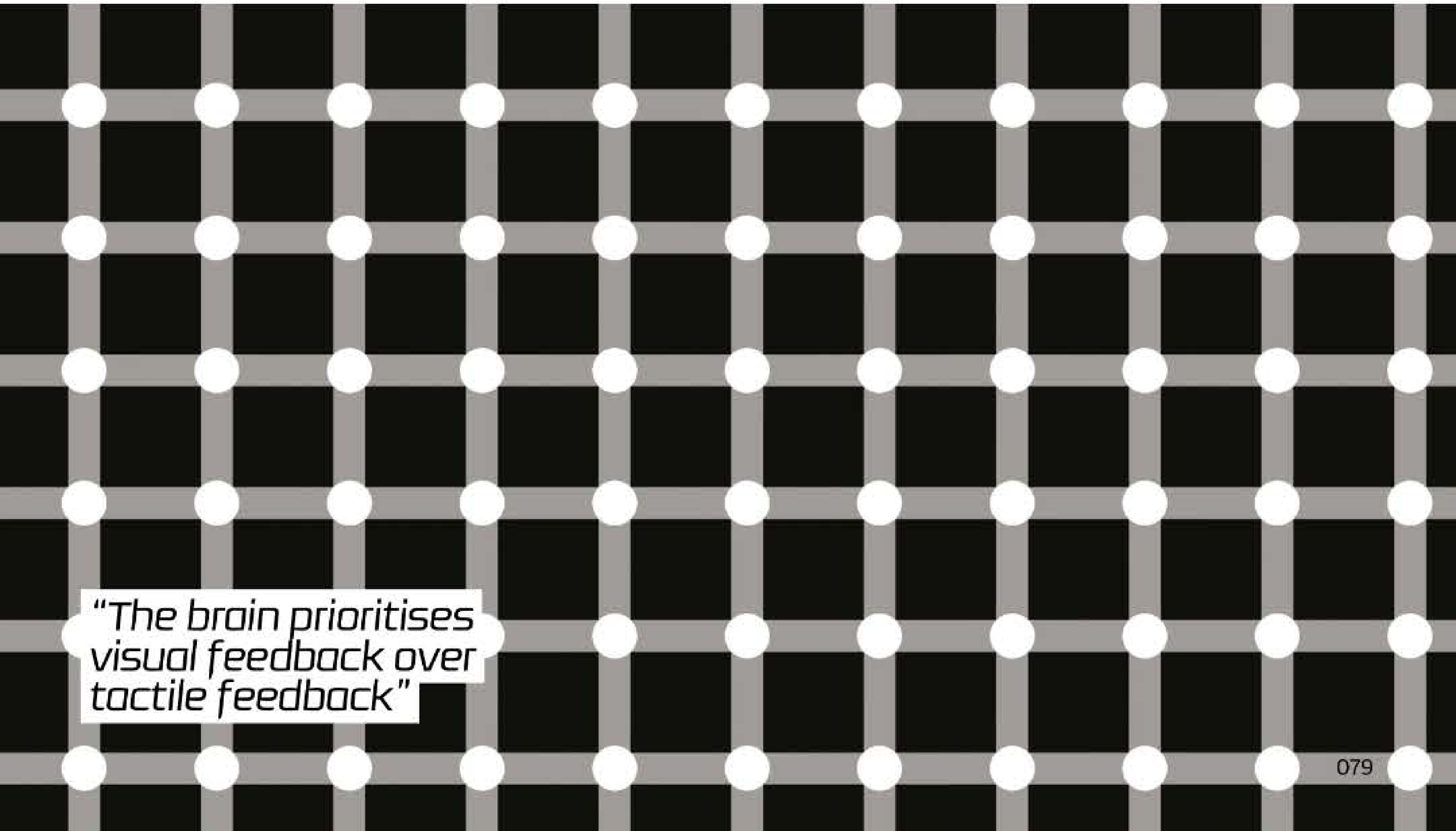
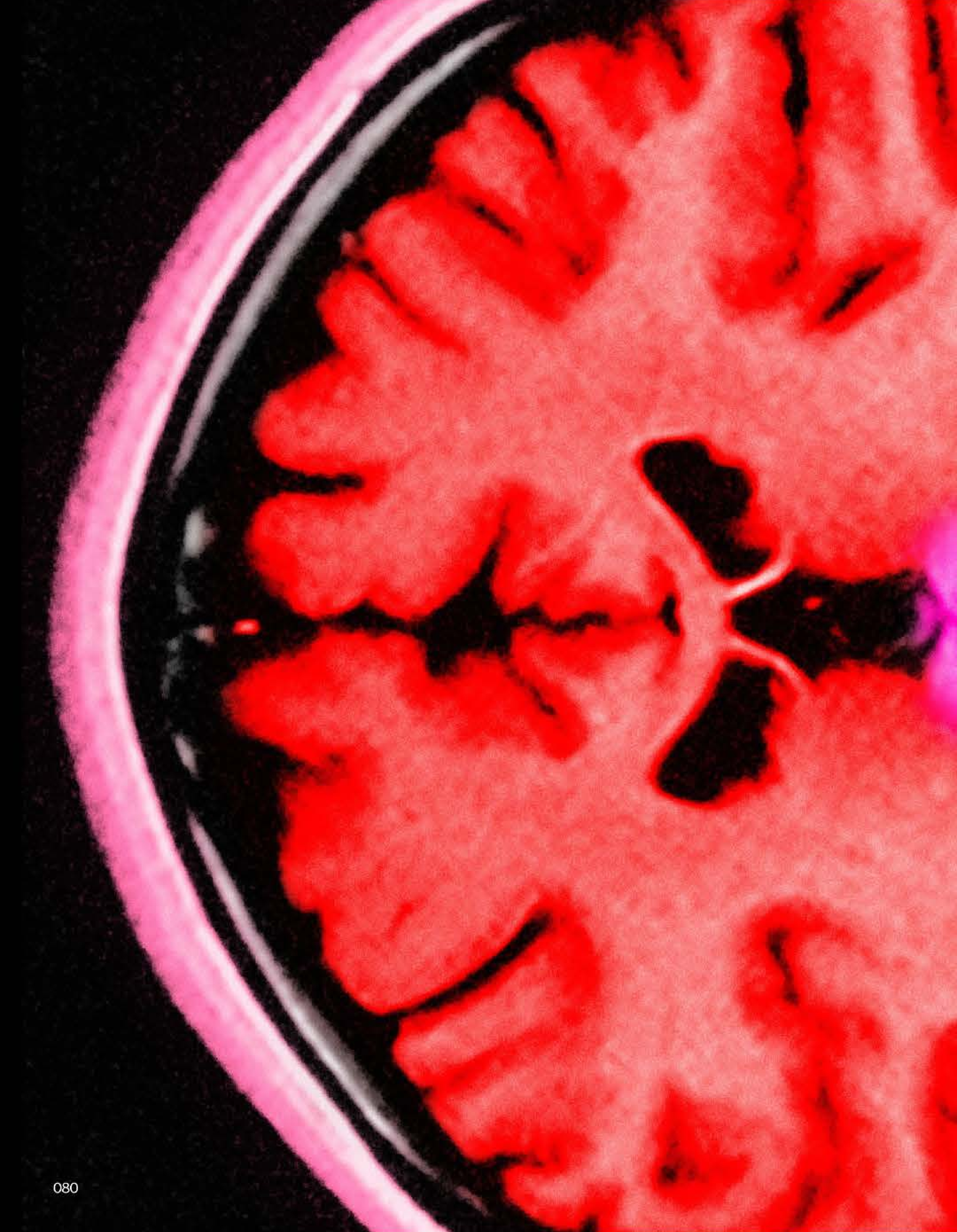
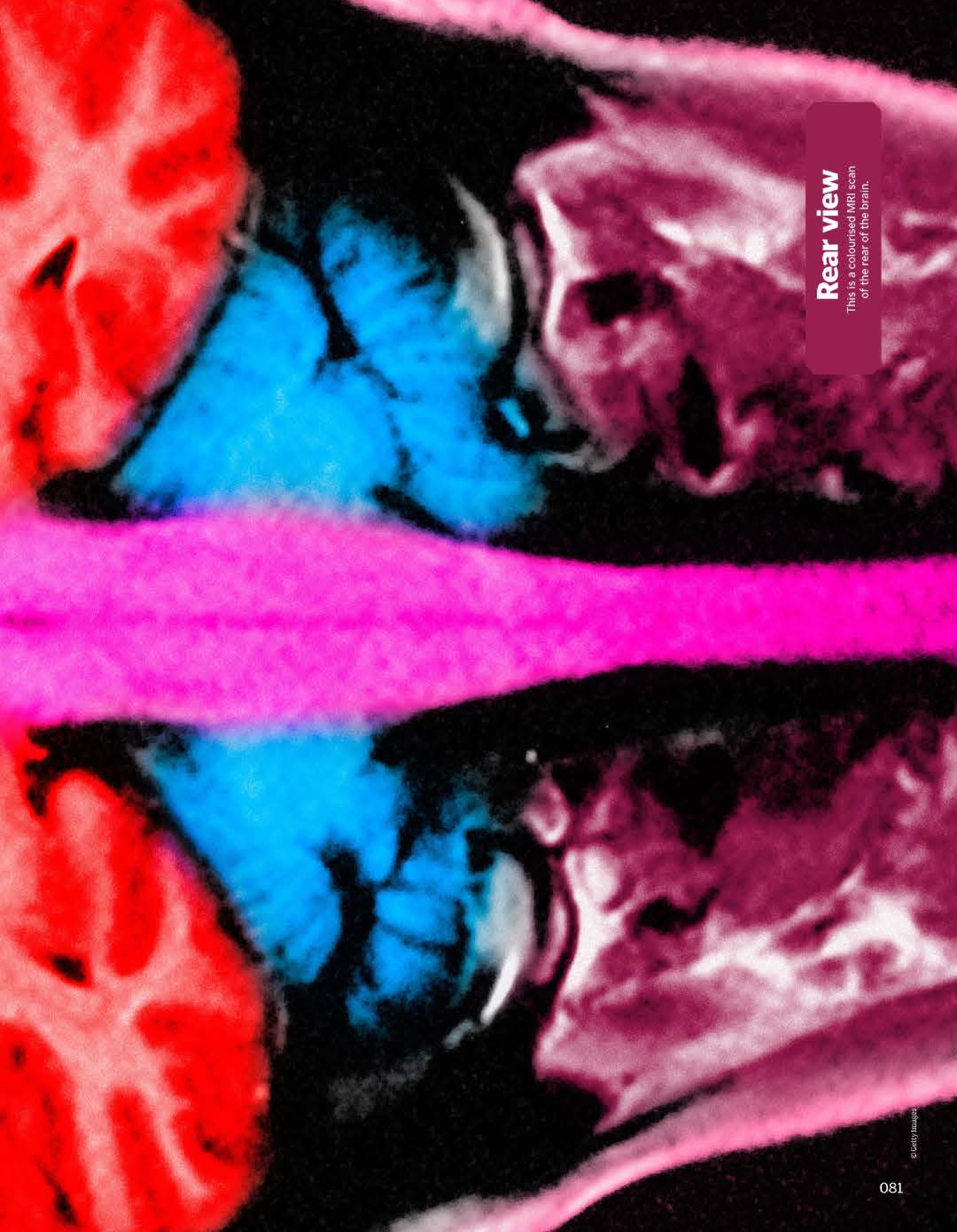


"The brain prioritises visual feedback over tactile feedback"





Rear view

This is a colourised MRI scan of the rear of the brain.

© Getty Images

THE PLACEBO EFFECT

How do sugar pills and saltwater injections trick the mind into healing the body?

Sugar pills ease depression, colourful creams numb the skin and saline injections make pain melt away. The placebo effect is a powerful healer, but how does it actually work?

In the 1890s, Ivan Pavlov discovered classical conditioning. His famous experiments taught dogs to associate the sound of a bell with the arrival of food. When they heard the noise, they started to dribble in anticipation. The same thing can happen to us with medicine. We make associations based on our experiences. If people take aspirin for a headache, they start to associate the shape and taste of the tablets with pain relief. Replace the pills with a placebo and the pain will still be lessened.

Placebos, also known as 'dummy' or 'inactive' treatments, are made from inert substances like saline, starch or sugar. They look and feel like the real thing but without any of the chemical effects.

The whole experience of receiving treatment can

help us to feel better. One study gave people a painkilling cream for two days and then replaced it with a placebo. The participants had experienced the cream working, so they expected it to continue helping. Also, the tone of voice of medical staff and the information they give people about what to expect during treatment can change the way people respond. In this instance, if the staff reassured them that the new cream would work, it did. But if staff told them that the cream would increase their pain, it actually made things worse.

The appearance of medicines can also shift our expectations. We associate bold colours like red, orange and yellow with a stimulant effect and blues and greens with sedation. Change the colour of a tablet and it'll change what people expect it to do. Similarly, if a pill costs more or comes in a branded box, we expect it to outperform its cheaper or generic counterparts. Even the name of the treatment has an impact. One study found that putting the word 'placebo' on a migraine medicine called rizatriptan reduced its impact. Calling a placebo 'rizatriptan' made it work better. Not surprisingly, calling the real medicine by its proper name worked best of all.

> "Change the colour of a tablet and it'll change what people expect it to do"

The placebo effect even works with surgery. The process of cutting the skin open and stitching it back together again can help people with knee pain, and fake operations can even ease heart pain caused by angina. Nothing actually needs to happen inside the body: the sights and smells of the hospital and the procedure of an operation can trick the brain.

The first neurobiological evidence for how the placebo effect works came in the 1970s. A famous study published in 1978 in the *Lancet* looked at what happened when people received a placebo painkiller after having a tooth removed. To find out how the placebo effect worked, half of the participants were also given a drug called naloxone, which blocks the activity of natural painkillers called endorphins.

In this study, naloxone stopped the placebo tablets from working, but only when people expected the placebo to help with their pain. When we expect a tablet to kill pain, the brain makes its own painkillers.

Current evidence now suggests that this effect starts in a part of the brain called the prefrontal cortex. This region handles complex behaviours and planning. When we expect to feel better, it boosts activity in nerve pathways that extend down into the spinal cord. MRI scans have shown that the placebo effect decreases blood flow in the parts of the spinal cord that let pain signals through. The endorphins triggered by taking placebo tablets help to stop pain signals from reaching the brain.

The placebo effect works less well on people with Alzheimer's disease, who often have damage to the nerve cells in their prefrontal cortex. The effect can also be blocked by placing magnets over the scalp, interfering with nerve signals in the front of the brain.

Anxiety can also block placebo pain relief. Studies have found that simply telling people that their pain will get worse can make it worse. It can even make non-painful touching hurt, a phenomenon known as allodynia. Reading about side-effects or looking diseases up on the internet can shape what we expect to happen, and this affects the brain.

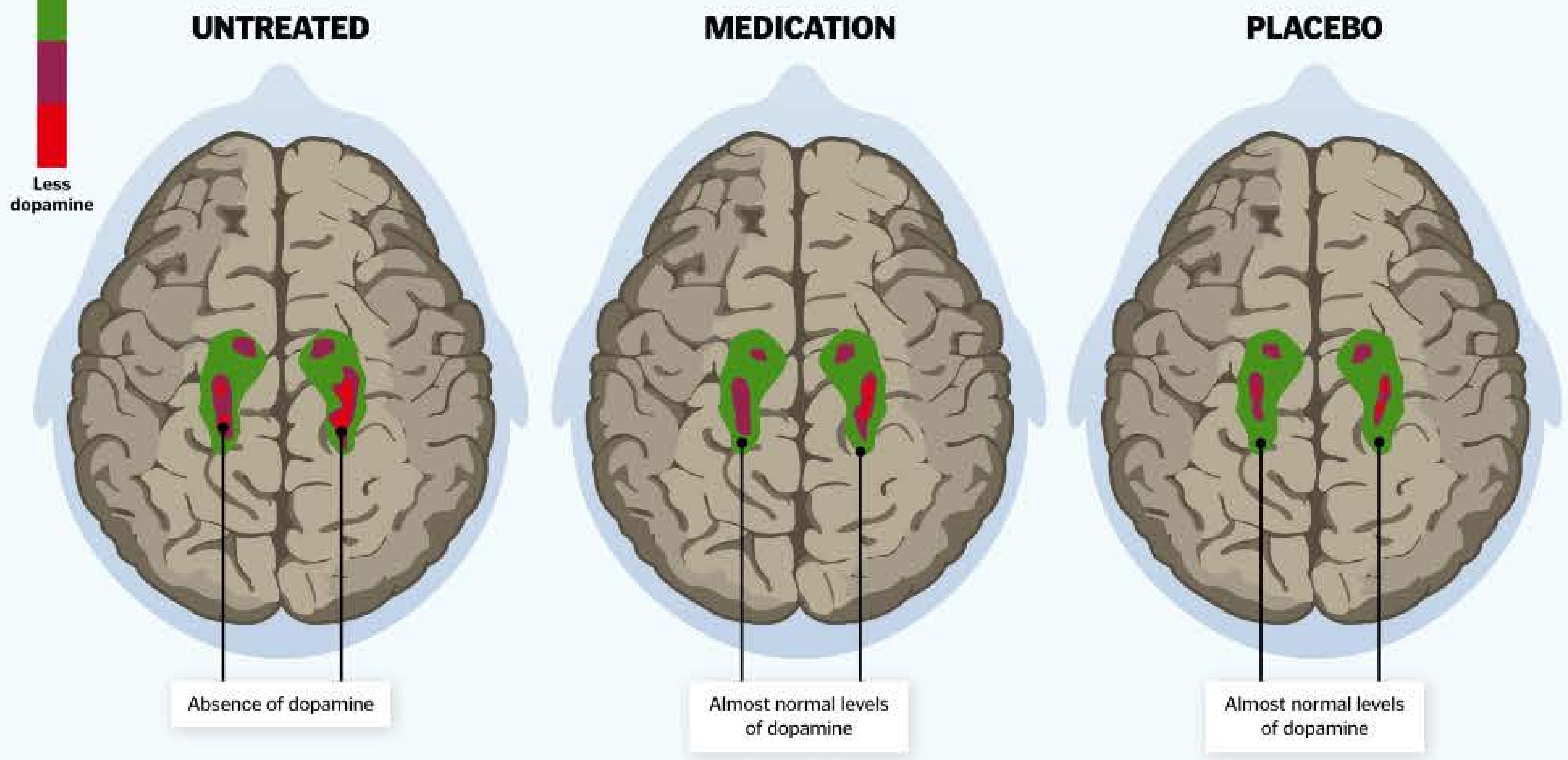
The second part of the brain's placebo system is a chemical messenger called cholecystokinin (CCK). It is produced when we are anxious. Blocking its activity with a drug called proglumide enhances the placebo effect, as does calming anxiety with the medicine diazepam.

Most of the work to understand the placebo effect has focused on pain, but dummy pills can affect other aspects of health and disease too. People with Parkinson's disease suffer damage to nerve cells in a part of the brain called the

All in the mind

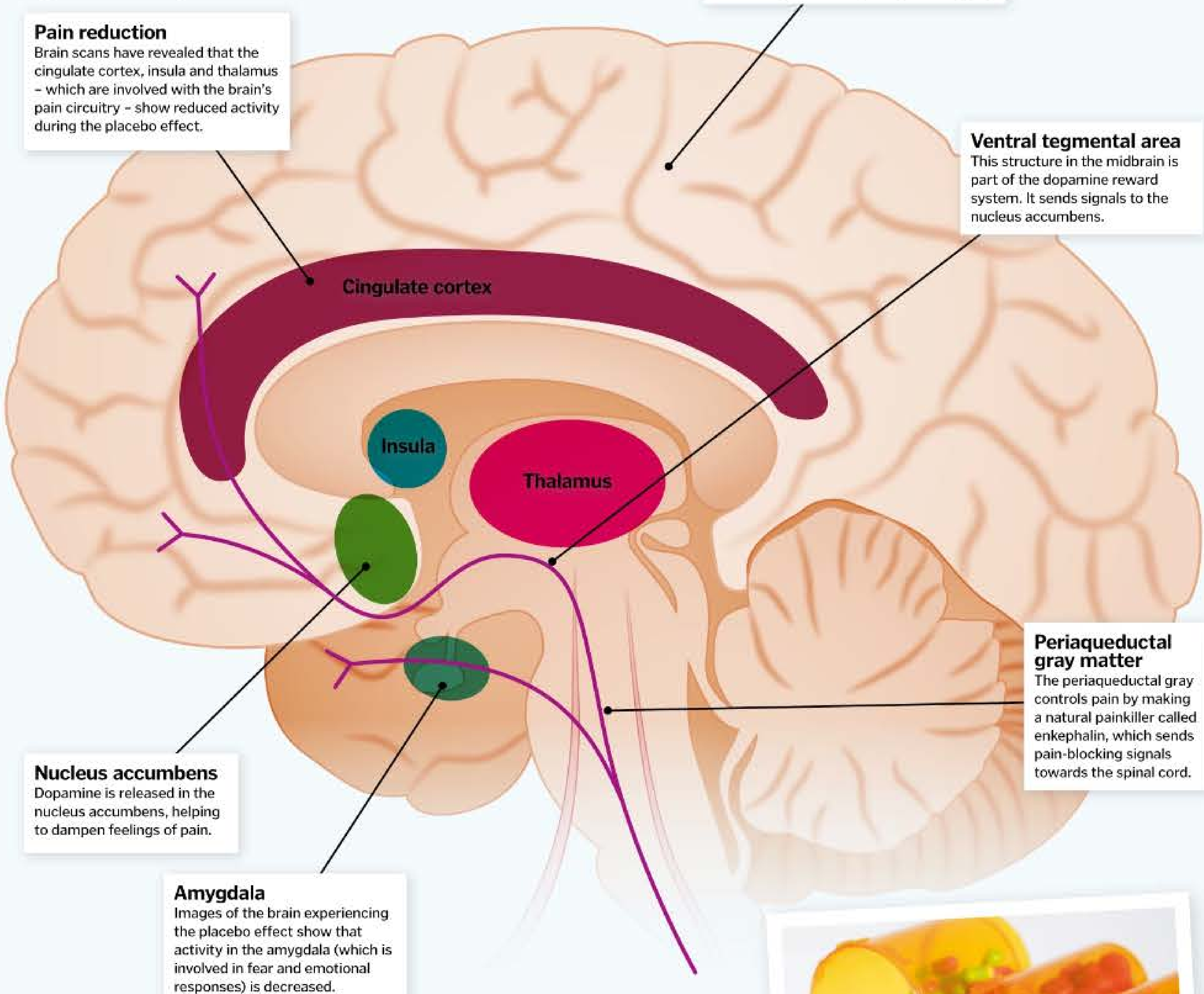
Despite its complexities, the human brain is surprisingly easy to fool

Parkinson's disease disrupts the brain's ability to produce dopamine. One study in 2010 found that the placebo treatment for Parkinson's could provide results almost identical to those achieved with the conventional medication, the drug L-dopa. The illustrations below represent a patient's brain scans from this trial.



Placebo pathways

The placebo effect depends on two separate sets of signals in the brain



Pain reduction
Brain scans have revealed that the cingulate cortex, insula and thalamus – which are involved with the brain's pain circuitry – show reduced activity during the placebo effect.

Cerebral cortex
The cerebral cortex is responsible for intelligence, memory and consciousness. It sends signals to the periaqueductal gray.

Ventral tegmental area
This structure in the midbrain is part of the dopamine reward system. It sends signals to the nucleus accumbens.

Periaqueductal gray matter
The periaqueductal gray controls pain by making a natural painkiller called enkephalin, which sends pain-blocking signals towards the spinal cord.

Nucleus accumbens
Dopamine is released in the nucleus accumbens, helping to dampen feelings of pain.

Amygdala
Images of the brain experiencing the placebo effect show that activity in the amygdala (which is involved in fear and emotional responses) is decreased.

Placebo in the brain

The science behind what really goes on inside our brain when we take a placebo

The placebo effect is all in the mind, and it's controlled by the parts of the brain that are responsible for managing anxiety, reward and pain. The cerebral cortex controls the highest brain processes, like consciousness and intelligence. The region at the front, known as the prefrontal cortex, handles complex behaviour, including our response to a placebo.

When we take a sugar pill believing it will help with pain, the prefrontal cortex passes messages to pain control neurons called the periaqueductal gray. These send natural, morphine-like painkillers into the brainstem, triggering the release of serotonin. More painkillers, known as enkephalins, then flood the spinal cord, where they block pain signals before they are able to reach the brain. At the same time dopamine streams into the brain's reward system, helping to reduce the perception of pain.

© Illustration by Jo Smolaga; Thinkstock; SPL

Some studies have suggested that many common drugs are just pricey placebos

substantia nigra. These damaged nerve cells stop producing dopamine, and this leads to problems with movement that worsen with time.

Placebo medicines can increase the amount of dopamine in the brains of people with Parkinson's disease. If they expect to receive real treatment and think that they will improve, dopamine levels rise on their own.

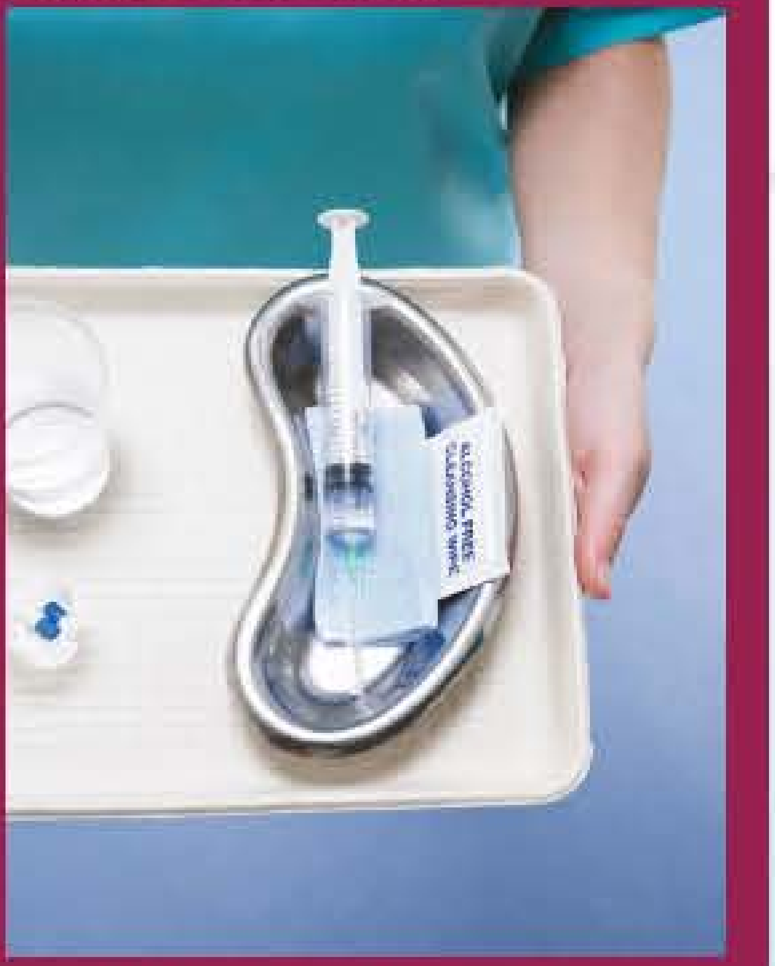
The immune system can also respond to a placebo. In 2002, the Goebel research group at the University of Duisburg-Essen in western Germany trained the immune system using a flavoured drink. They repeatedly dampened immune activity using an immunosuppressant called cyclosporin A. Each time they accompanied the treatment with the drink. After the conditioning was complete, they didn't need the drug any more. The drink was able to suppress the immune system on its own.

In 2008, they repeated the experiment with allergies. This time they gave antihistamines with the flavoured drink. Incredibly, not only did the drink make people feel better even when the antihistamines had been removed, it also reduced the activity of allergy-inducing immune cells called basophils.

Placebos in trials

The placebo effect is powerful in its own right, but to date it's been most useful as a way of testing new treatments. Studies of the placebo effect have shown that receiving a tablet and expecting it to work can be enough to make you feel better. So how do we know if a new treatment is actually working? The answer is to give half the patients the real thing and give the other half a sugar pill that looks exactly the same, then compare the two.

This works best if neither the patients nor the doctors know which treatment they are getting, a technique called 'double blinding'. This way no one can be quite sure what to expect. If the people receiving the real treatment do better than the ones on the sugar pills, you can be sure that it's not just the placebo effect at work.



Placebos are made to look and feel the same as the real treatment

The nocebo effect

While placebos can be incredibly helpful, they can also result in some unwanted side-effects

The nocebo effect is like the placebo effect but in reverse. If we think that sugar pills are the real thing then they can cause side-effects just like real medicines. It's hard to study the nocebo effect, but in 2014 Sara Planès and her colleagues at the Grenoble University Hospital in southeastern France gathered 86 studies together and reviewed the evidence.

They found that symptoms of the nocebo effect tend to be non-specific, like nausea, dizziness and headache. They also discovered that it affects women more than men, and people with depression and anxiety are particularly vulnerable. The team were also able to confirm that, just as with the placebo effect itself, the nocebo effect is partly psychological and partly neurobiological.

Conditioning can make us expect side-effects, and while chemical changes in our brains can make pain feel better, they also have the potential to make it worse.

Placebos have side-effects and can do harm as well as good

> "Every time we receive medical treatment, part of the experience is psychological"

We still don't fully understand the placebo effect, but there's no escaping it. Every time we receive medical treatment, part of the experience is psychological, and medical professionals are already using this knowledge to help us get better.

There are two types of placebo. Pure placebos do nothing chemical to the body, like sugar pills or saline injections. Impure placebos are treatments that do have chemical effects but not for the condition for which they are being used. Antibiotics are an example; they treat bacterial infections but are often prescribed for flu even though it's caused by a virus.

A recent survey of UK GPs found that, though few use pure placebos, three-quarters prescribe impure placebos to their patients at least once a week. Examples can include giving people nutritional supplements, probiotics, antibiotics and alternative medicines. Alternatively, it can entail booking patients in for non-essential tests. The most simple option is just using the power of positive suggestion.

There is an ongoing debate about whether this is ethical, but similar studies in other countries have found that placebo use is widespread. The more we understand how it works, the better we will be able to harness its power.

A saline injection has a more powerful placebo effect than a sugar pill

The pharmaceutical industry will be worth around $1.5 trillion by 2022

> "Reading about side-effects or looking diseases up on the internet can shape what we expect to happen, and this affects the brain"

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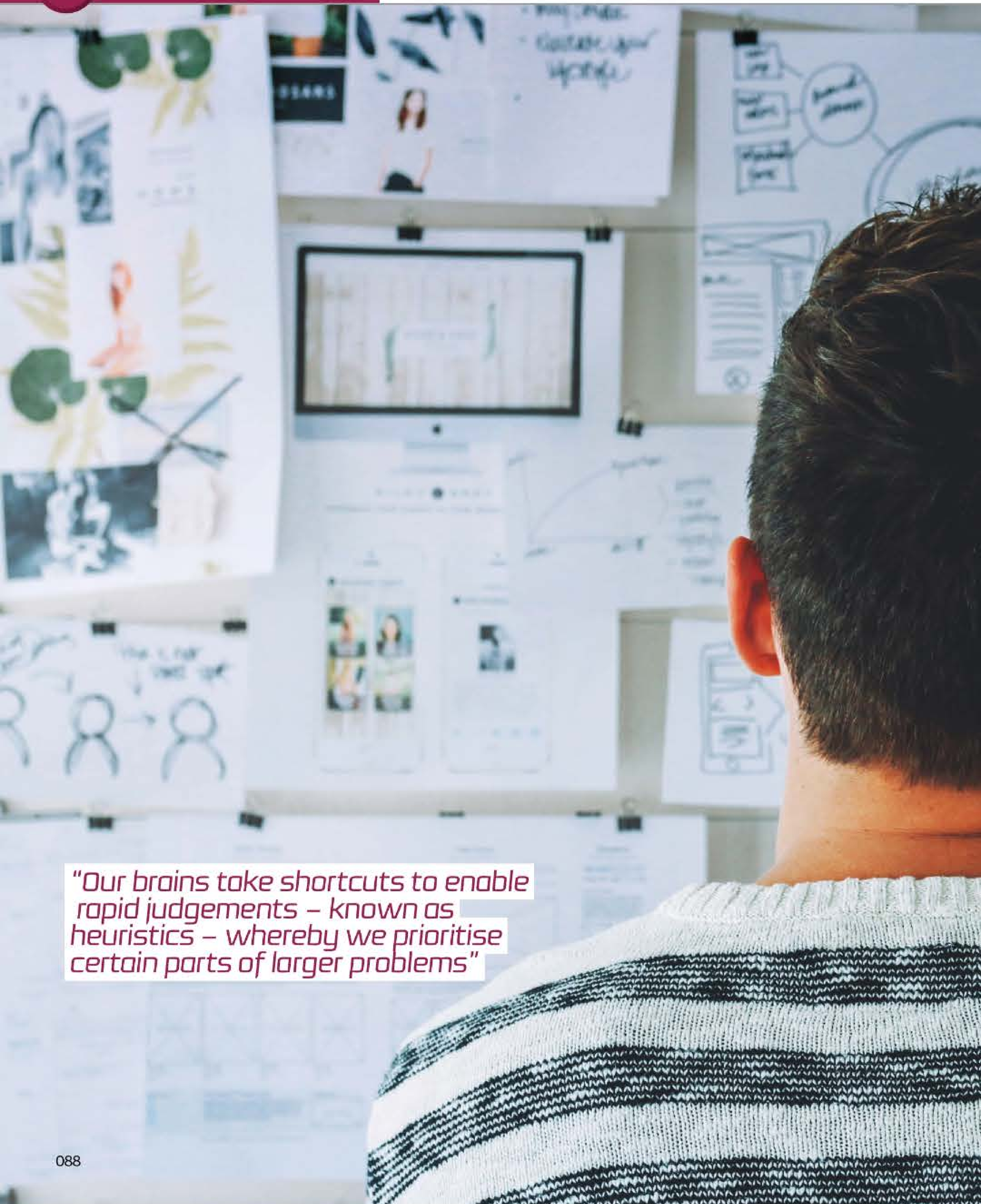
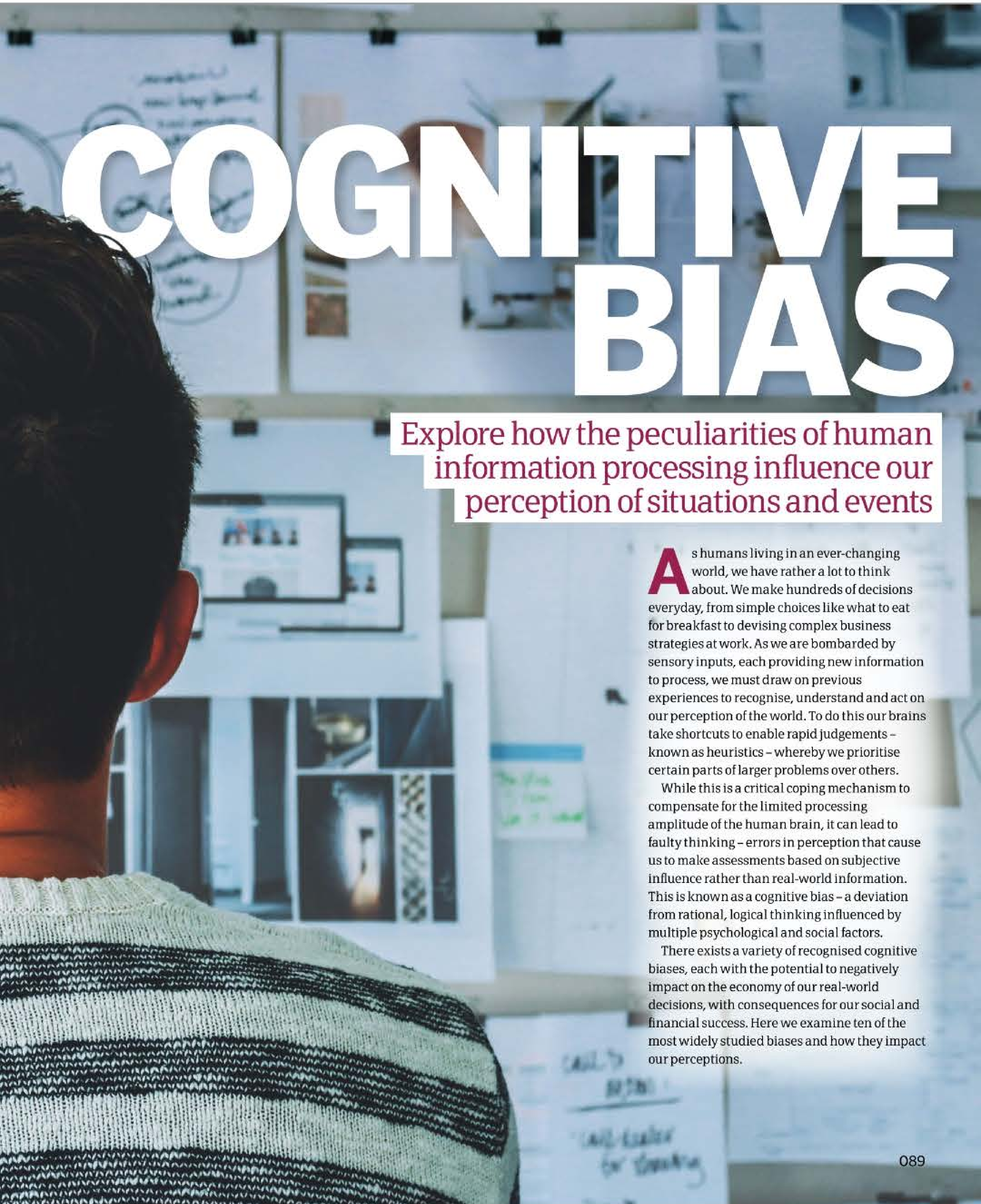


"Our brains take shortcuts to enable rapid judgements – known as heuristics – whereby we prioritise certain parts of larger problems"



COGNITIVE BIAS

Explore how the peculiarities of human information processing influence our perception of situations and events

As humans living in an ever-changing world, we have rather a lot to think about. We make hundreds of decisions everyday, from simple choices like what to eat for breakfast to devising complex business strategies at work. As we are bombarded by sensory inputs, each providing new information to process, we must draw on previous experiences to recognise, understand and act on our perception of the world. To do this our brains take shortcuts to enable rapid judgements – known as heuristics – whereby we prioritise certain parts of larger problems over others.

While this is a critical coping mechanism to compensate for the limited processing amplitude of the human brain, it can lead to faulty thinking – errors in perception that cause us to make assessments based on subjective influence rather than real-world information. This is known as a cognitive bias – a deviation from rational, logical thinking influenced by multiple psychological and social factors.

There exists a variety of recognised cognitive biases, each with the potential to negatively impact on the economy of our real-world decisions, with consequences for our social and financial success. Here we examine ten of the most widely studied biases and how they impact our perceptions.

Survivorship bias

The tendency to ignore absent information and only ever plan for the best

It can be a challenge to consider information that is not observable in our assessment of a situation. Where a person or object is not present, humans will naturally focus on those that we can see and form an opinion based solely on that condition. Survivorship bias refers to situations where we make assumptions based on the apparent success of a group of objects or people but fail to recognise that our sample is not representative of subjects that have been excluded.

Looking at data of injuries sustained by car crash survivors, we may conclude that the worst injuries occur when sitting in the front seats, when in fact this data does not include people who were sat in rear seats and were killed in the accidents. To say better crash protection should be installed in front seats would be a common but clearly false conclusion in this case.

In a city of predominantly new buildings, the older ones remaining are the best examples of their generation, yet observers could wrongly assume older buildings were all constructed to last longer

Endowment effect

The attribution of greater regard for that which we already own, independent of actual value

We can all find ourselves becoming sentimentally attached to objects, even when there is no obvious reason to value these so highly. The endowment effect describes a common situation where people place greater value in something they already own than something they are yet to acquire, due to an emotional bias.

In psychological studies, such as that by Kahneman, Knetsch and Thaler in 1990, it has been regularly observed that participants will demand a far greater price for something they perceive as their property than the amount they are willing to pay for something of equivalent value. It has been suggested that this is a form of loss aversion – as a species we experience greater anxiety in losing something than we feel pleasure from gaining an equal reward, although the motivation is unclear.

An evolutionary suggestion is that in the past, natural selection favoured humans who were less willing to part with property when there was less choice of people to trade with to find a better deal. In economics this can be problematic in the modern day, as holding onto something unprofitable, such as inherited shares in a failing company, is irrational and can prove financially disastrous.

Participants in studies of the endowment effect were often willing to pay less for an item than the minimum they would expect to be paid for the same object

Hyperbolic discounting

Immediate rewards don't always offer the greatest benefits, but you are still more likely to select them

Willpower plays an important part in society and is often seen as a measure of strength of character by our peers. However, the choice to accept a smaller reward sooner rather than a larger return in the future is a far more complex behaviour than may be immediately obvious. There is a tendency among humans to perceive future rewards as less attractive, attributing less value the more temporally distant this becomes. We make inconsistent choices over time, even when presented with the same information.

In evolutionary terms this can be explained by the choices early humans would have experienced – with immediate risk, such as starving to death, it made more sense to select instant solutions. Today, however, where we need to think longer term, such as saving for a pension, this can be ineffective thinking – something to remember the next time you're tempted to buy another expensive pair of shoes.

If you have ever looked back and regretted a decision you made for an instant reward, this is likely hyperbolic discounting at work. Strength of the reward is an influencing factor

Clustering illusion

How we interpret groups of events can affect our ability to predict future probabilities

Sport and gambling are two activities that are most obviously affected by cognitive biases and are two of the most studied. This is largely due to the great influence individual perception can have on our ability to see patterns in events and predict future outcomes.

The clustering illusion bias is centred around the human predisposition to see events closely distributed in time as related, when in fact such events are random. The most famous example of a study of this effect is a 1985 investigation carried out by psychologists Gilovich, Vallone and Tversky, of Cornell and Stanford Universities, on the 'Hot Hand Fallacy' – the belief that in basketball a player is more likely to score if previous attempts have been successful.

While confidence can improve performance, this incorrect assumption is largely caused by an overestimation of our ability to predict random events, something that is actually impossible. When we have little information to rely on (a small sequence of attempts at something) we assume events will be more spread out, so when a cluster occurs, such as a string of successes, we perceive it as non-random. This makes us overconfident in predicting such a sequence will continue for future attempts.

A previous series of successes does not predict future events, but humans often see patterns where none exist. This can produce unfounded confidence in a continued sequence

Confirmation bias

Our process of gathering information to form our opinions is not as impartial as we may believe

While we like to believe that we are open-minded and observe all of the available information on a subject before drawing a conclusion, the reality is that this doesn't always happen. Confirmation bias is a flaw in how we collect, process and recall information, which suffers from a tendency to favour that which confirms pre-existing beliefs.

Since decision-making falls back on experience and preconceived ideas, it can be uncomfortable for us to reject what we think we already know and accept a new truth. We therefore pay greater attention to data that reaffirms our beliefs and ignore facts that question them. This can have significant implications in areas such as the medical profession, where a doctor diagnosing a patient may recognise initial indicators of an illness and fail to seek, recognise and act on other diagnostic markers that may disprove their hypothesis. Multiple doctors observing the same information but with opposing preconceived ideas may draw very different conclusions due to their unconscious choice to dismiss disaffirming facts.

With an influence in stereotyping, confirmation bias can make us see patterns in data where there are none and fail to see those that are present in new information.

Availability heuristic

The bias towards recent, easily remembered information when assessing importance and relevance in new situations

Memory recall is a critical brain function, yet we experience so much sensory input that we rely on mental shortcuts to identify familiar stimuli. The availability heuristic, first described by Amos Tversky and Daniel Kahneman, is the process of unconsciously prioritising most recently acquired information, biasing assessments of a situation on that which is most easily recalled.

Research has shown how participants overestimate the relevance of information that they are able to easily remember, even if this is a first impression of the broader situation. The likely thought process is that we assume if information is readily available to recall it must be more important than that which does not quickly come to mind. While cognitively useful, the implications for judicial decisions, education-curriculum design and learning performance are significant, where the methods for conveying information in a lesson and then demanding recall in an exam situation are not compatible.

In a courtroom setting the availability heuristic may cause the opinions of the jury to be swayed by time elapsed since a crime and the order in which information is presented

Stereotyping arises from our comparisons to previously observed information. The role of a pilot is often seen as a predominantly male job even though there are many female pilots today

Stereotyping

While it may be associated with discrimination against minorities, stereotyping does have an innocent cognitive function

Stereotyping is one of the most recognised cognitive biases and carries with it many negative connotations. The stereotyping of people often results in the feeling of judgement within the subject group, and there are sinister implications for unreasonably assuming all members of that group are the same. However, as with many biases, there is a heuristic component, that allows rapid identification of people, places and objects.

You might find yourself instinctively asking a person in an airline's uniform for help with flight information, for example, assuming they will be an expert. This stereotype provides a rapid solution to a potentially complex real-world problem. With such social categorisation we learn to identify people less as individuals and more as part of a social group. We may be aware of this or it may be a subconscious process – known as explicit and implicit stereotyping respectively.

As a type of confirmation bias it can be difficult to challenge our own beliefs about a group. This explains how easy it is to link emotional responses to our stereotypes (develop a prejudice) and in turn alter our social behaviour (discriminate against a group). We naturally seek characteristics that reinforce our assumptions.

In a truly random condition, previous events cannot be used to predict future outcomes, although this is a common thought process in situations where we have little control

Gambler's fallacy

An opposite effect to clustering illusion, this bias also results in faulty expectations about future events

Gambling creates complex responses in humans. There is a clear emotional investment in the outcome of a bet, yet there are more deep-seated psychological processes at work. Gambler's fallacy is the incorrect reasoning that after a series of repeated events, such as scoring a red on a roulette wheel, a different event becomes more likely – scoring a black, for example. This is opposite, yet related to, the hot hand fallacy, arising from a misperception about small sample sizes, where we assume shorter series of random occurrences yield similar results to longer sets. Where a winning or losing streak is encountered, we expect an inverse event to create balance. Tversky and Kahneman called this the representativeness heuristic – comparison to previous experiences of event sequences.

In reality, where events are discrete, one will not affect the probability of the other occurring. Suggested biological causes are the stimulation of parts of the frontal and parietal lobes of the brain involved in decision-making, judgement and reasoning – zones attributed to increased risk-taking after experiencing a loss. The bias is sometimes dubbed the Monte Carlo fallacy after a famous night of roulette losses in 1913 in the casino of the same name.

When purchasing a car priced lower than anticipated, we might fail to adjust this expectation by studying the market for more information on the best possible price

Anchoring bias

Even business-savvy people can fall foul of this bias towards initial information

As other cognitive bias examples have demonstrated, humans rely heavily on impressions of a situation to quickly make assessments. However, anchoring is another shortcut that can prove inefficient in the modern world. With this bias, we fix on the first piece of information we receive and use this as a basis for judging all subsequent facts. The common example is being given a lower-than-expected price for a product and immediately accepting this while missing out on potential better deals elsewhere.

Another Tversky and Kahneman investigation suggested that we often incorrectly adjust expectations from the anchor, affecting our judgement. Even with experience and when armed with awareness of anchoring in action, it can prove difficult to avoid, influencing multiple decisions of a financial, social or professional nature. While it is possible to illustrate the effects, it has proven a challenge to pinpoint the greatest psychological causes.

Risk compensation

Does perceived safety yield increased complacency? This question has significant implications for hazard management

Every decision we make is a process of weighing up costs and benefits. Where we deem the potential costs too high to justify an action we may decide not to engage in that behaviour. Risk compensation is a hypothesised mental adjustment whereby we take greater risks when perceived safety is increased, thereby nullifying those safety measures. Closely associated with this theory is Professor Sam Pelzman, who suggested that road safety strategies are useless, since with increased protection comes increased risk taking by drivers. This became known as the Peltzman Effect.

While this has been widely disputed, another study by Gerald J S Wilde noted decreased traffic deaths in Sweden after a change in driving side. Once drivers became accustomed to right-hand driving, fatality rates increased once more, an effect termed risk homeostasis – the continuous balancing of perceived and actual danger. This is likely due to our predisposition to seek the action that will yield the greatest reward with the least effort, a trait that poses a challenge in hazardous workplaces. Recurrent training is often required to maintain safety. Knowledge of risk compensation can also help in marketing – fostering a safe online marketplace can encourage greater sales from clients.

There is still dispute among the scientific community about whether risk compensation nullifies safety measures, but confidence has been shown to impact on the occurrence of risky behaviour

DAMAGE AND DISEASE

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Discover how the brain is affected by neurological diseases and how science is seeking to cure them

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Meet the psychologists who discarded ethics in their bid to understand our primitive sides

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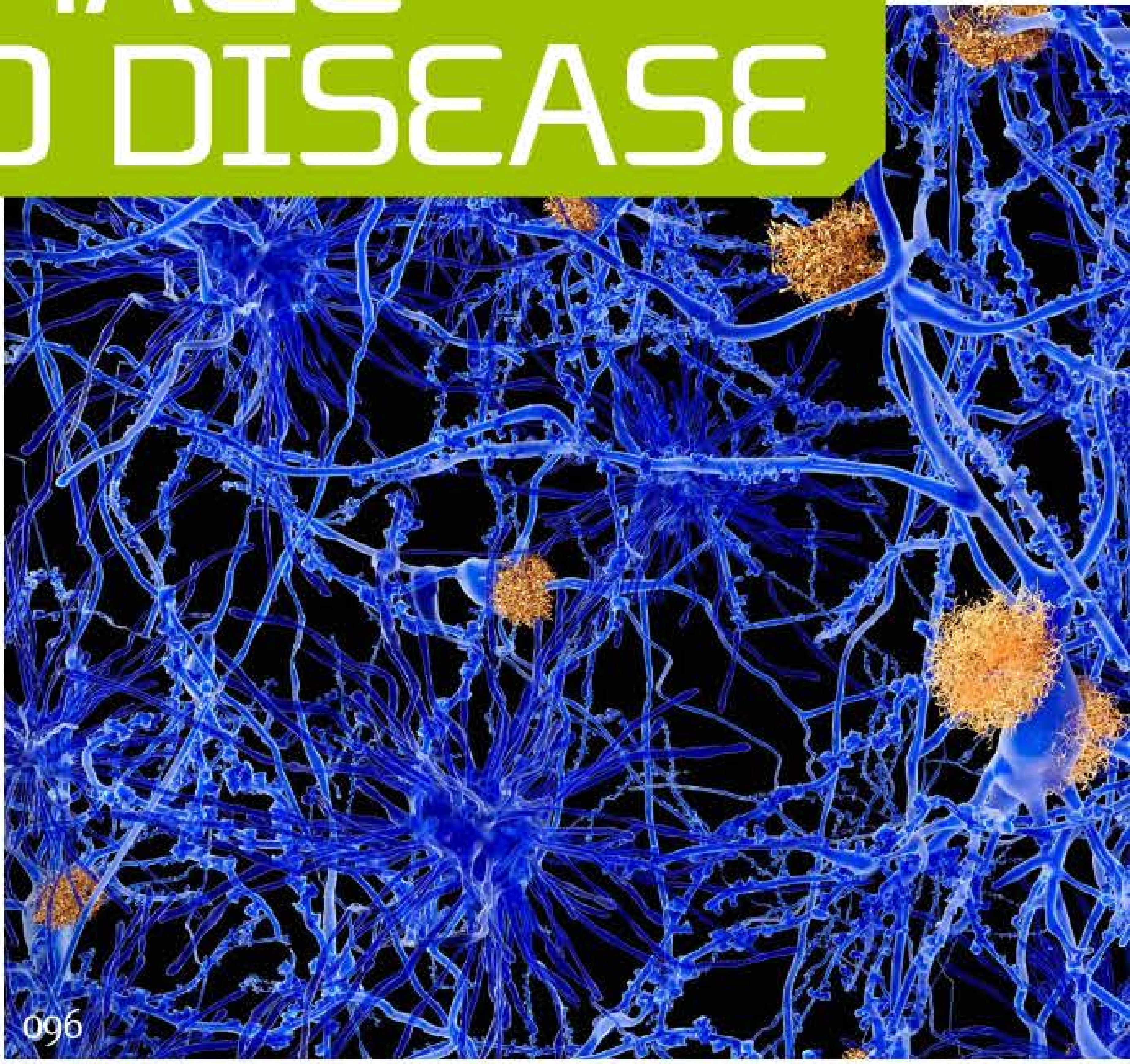
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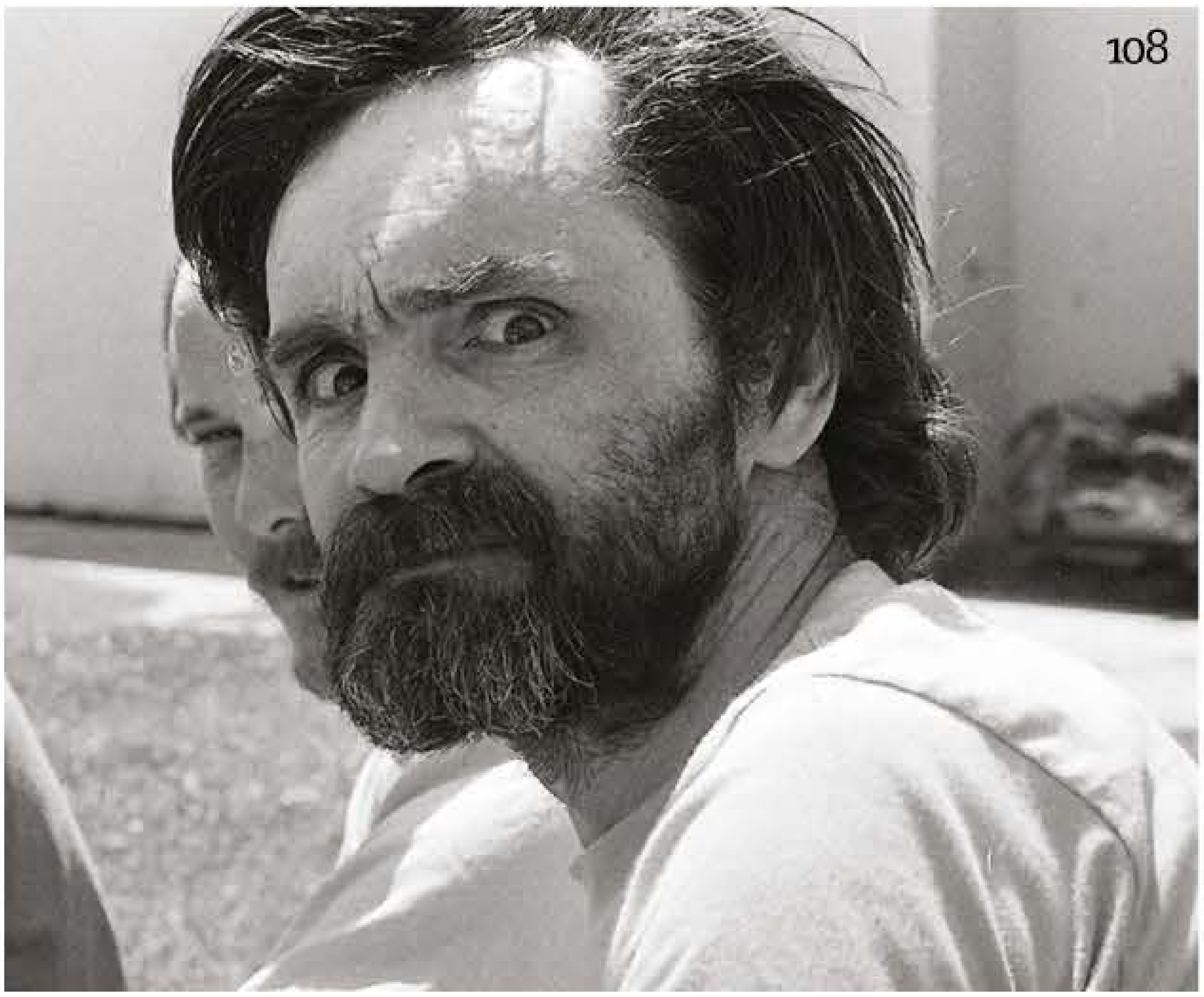
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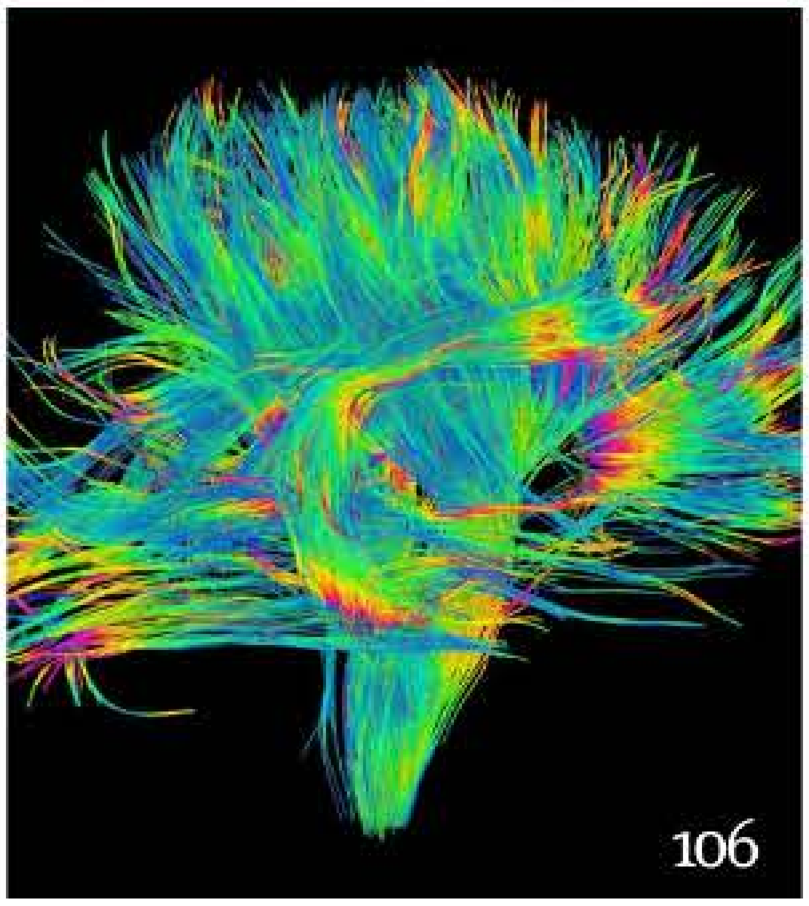
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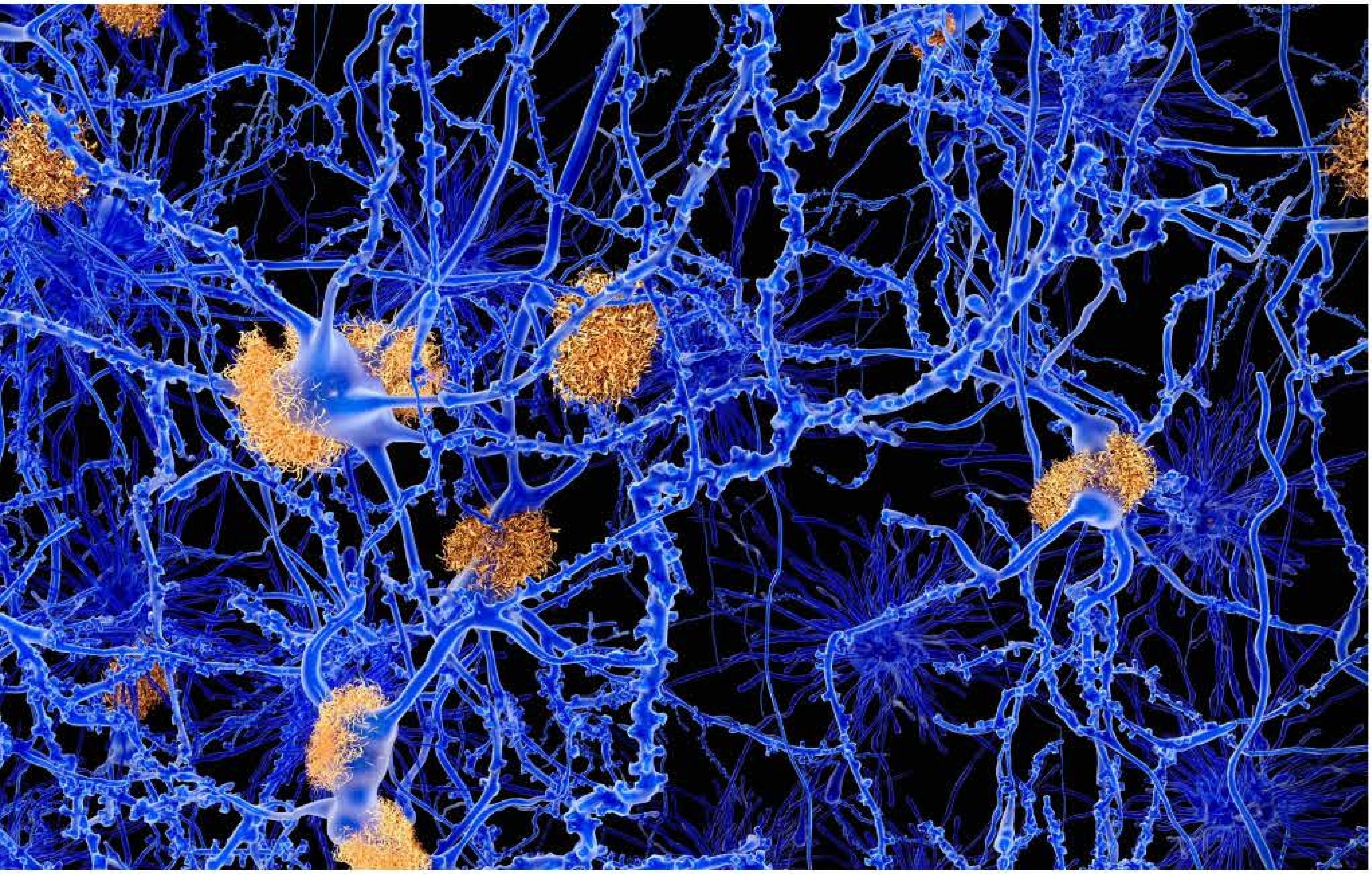

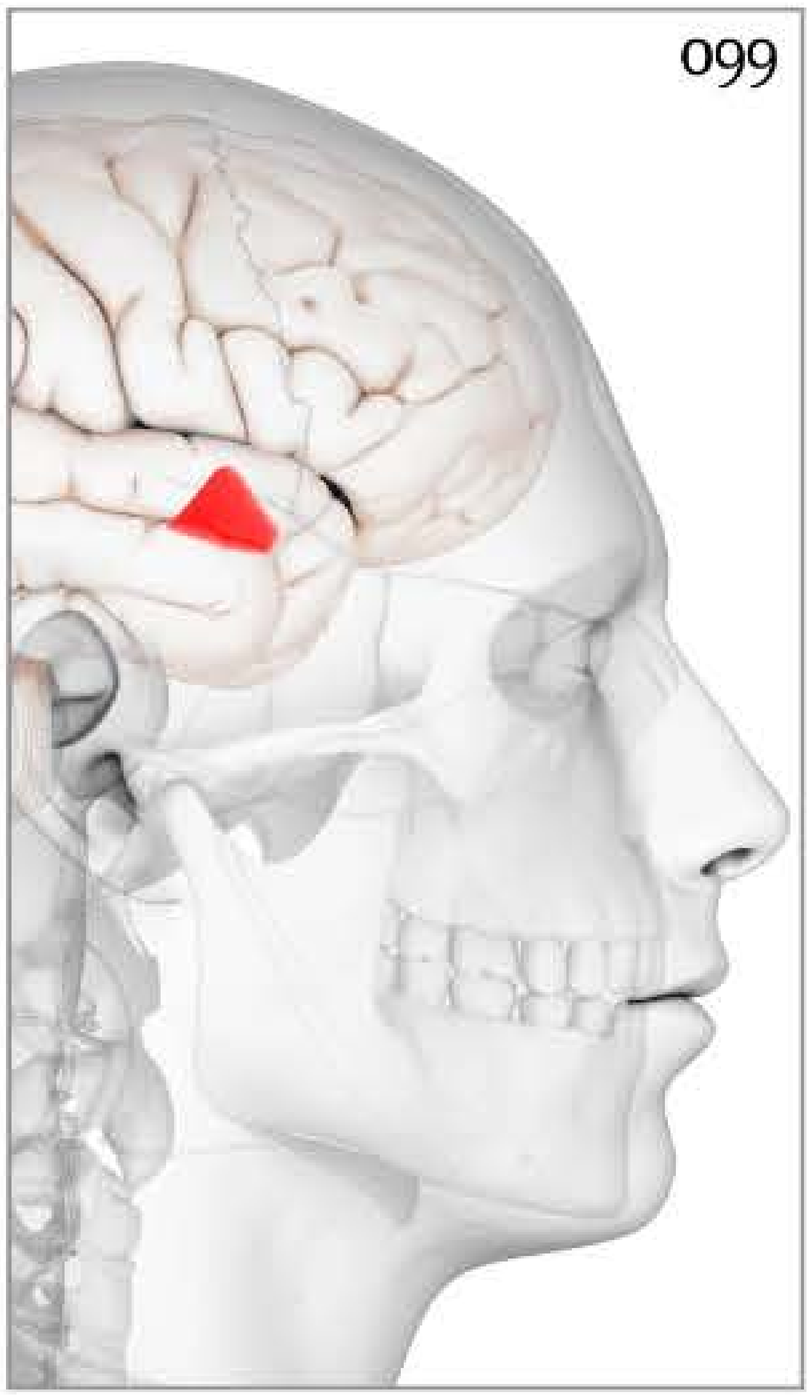

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DISEASES OF THE BRAIN

The brain is a finely tuned machine, but unlike a machine, when the brain malfunctions, it can be incredibly difficult to fix

Words by **Baljeet Panesar**

The brain is divided into three main parts: the cerebrum, cerebellum and the brain stem. The largest is the cerebrum, which consists of four lobes: the frontal, parietal, occipital and temporal lobes. Each region is associated with different functions, and they work together to control our bodies.

The brain has an estimated 86 billion nerve cells, or neurons, through which information is constantly transmitted to different parts of our body, allowing us to make sense and respond to the world around us. Between different neurons are trillions of miniscule gaps called synapses, where signals are passed from one brain cell to the next.

Given that the brain is such a highly complex and specialised organ, when it is injured or damaged the results can be devastating. In England alone it's estimated that 14.7 million people suffer from some type of neurological condition, including stroke, epilepsy, dementia and narcolepsy.

In this feature we will take a look at some of the most serious diseases that can afflict the human brain, the effects they can have on people's lives and the efforts being made to treat and, hopefully one day, cure them.

Epilepsy

Seizures are caused by disrupting a neuron's ability to transmit normal electric signals

Around one in 100 people have epilepsy, making it one of the most common neurological conditions in the UK. Epilepsy is one of the world's earliest recognised conditions – written records date back to 4000 BCE – and the Greek philosopher Hippocrates was the first person to propose the idea that epilepsy originates in the brain.

A seizure occurs when neurons fire too many electrical signals, causing the brain to mix up the messages, which temporarily disrupts the way that it functions. There are over 40 different types of seizure, each of which affect people with epilepsy in different ways depending on which part and how much of the brain has been affected. Some people remain completely conscious and experience twitching limbs. Others may lose consciousness, fall to the ground and convulse violently. Seizures only tend to last for a few seconds or minutes, and some sufferers have no recollection of them.

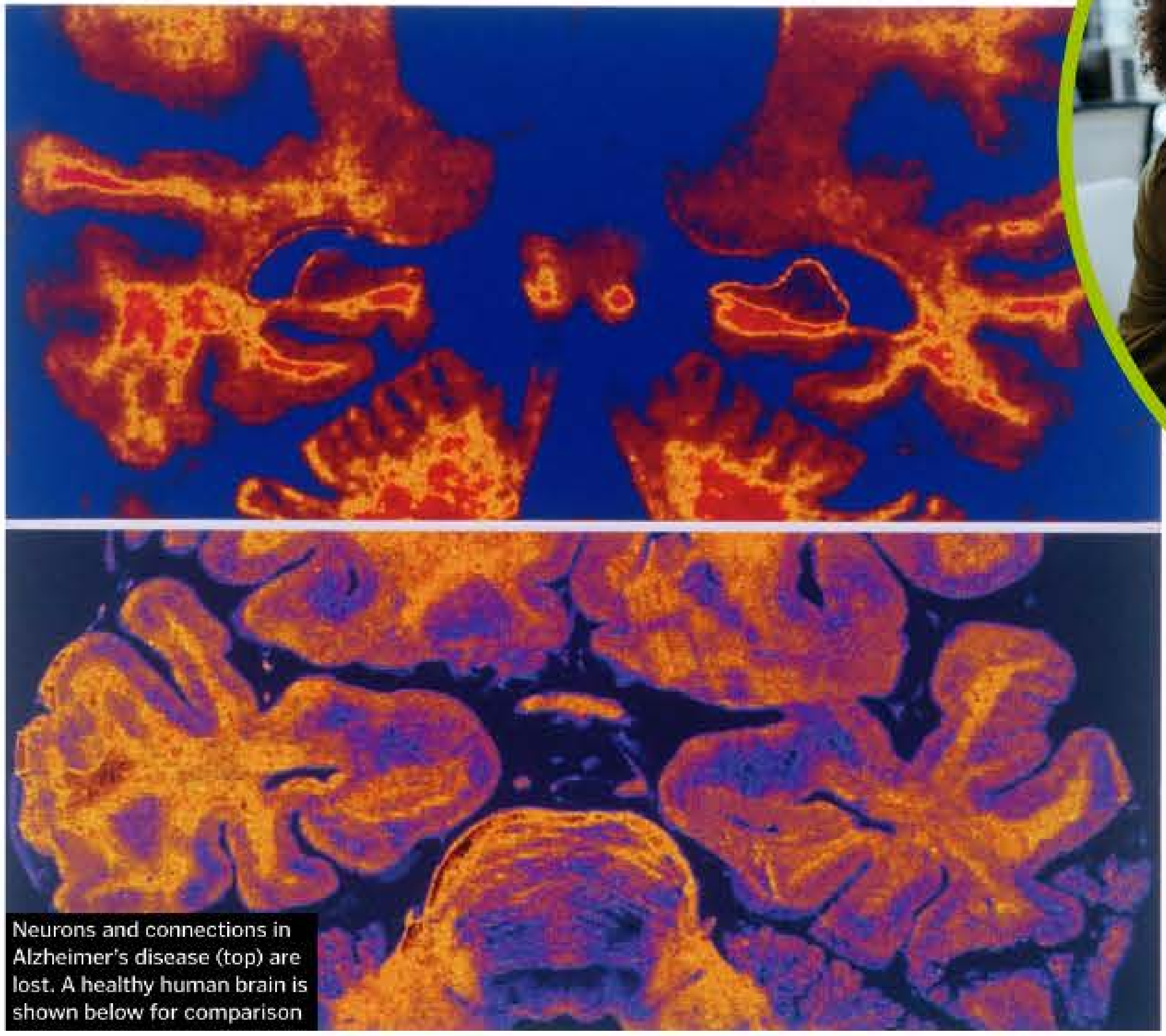
Epilepsy cannot yet be cured, but there are several treatments available that help people have fewer seizures. Epilepsy is mainly treated with medicines called anti-epileptic drugs (AEDs). Phenobarbitone was the first AED to be used in the treatment of epilepsy in 1912, but today many AEDs are available. Other treatment options include surgery to remove a part of the brain that is causing the seizures and Vagus Nerve Stimulation (VNS) therapy. VNS involves implanting a small device in the chest that sends regular electrical pulses to the brain via the vagus nerve to suppress seizures.

In generalised epilepsy, the entire brain is affected by abnormal brain activity

Seizure dogs are trained to respond to a person having an epileptic seizure

Alzheimer's disease

Alzheimer's destroys brain cells and has a devastating effect on memory



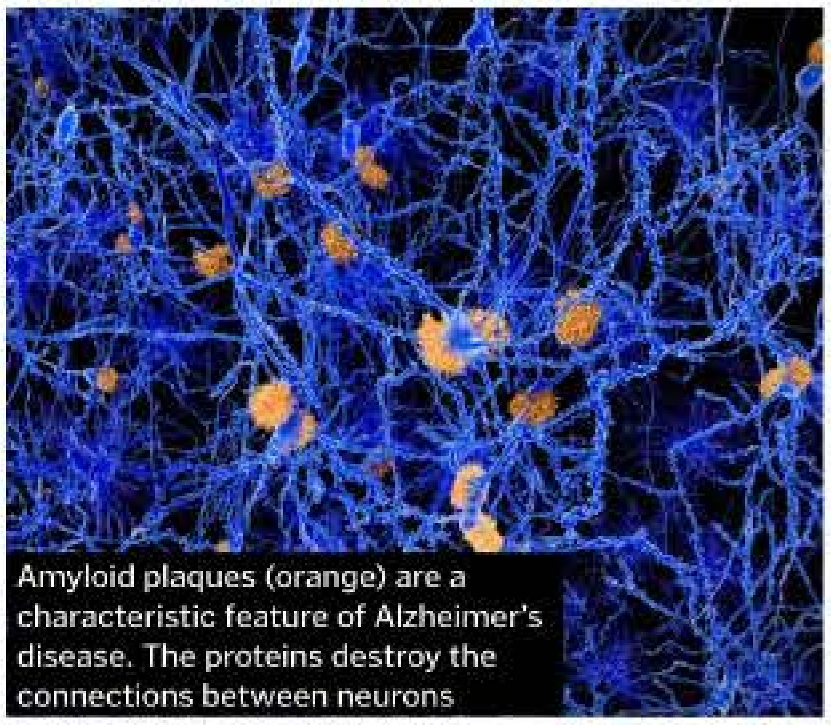
Neurons and connections in Alzheimer's disease (top) are lost. A healthy human brain is shown below for comparison

Alzheimer's disease is the most common form of dementia (a name given to symptoms that affect memory, thinking and communication) in the UK. The brain tends to shrink as we age, but we do not naturally lose neurons in appreciable numbers. However, in Alzheimer's disease abnormal protein plaques build up in and around brain cells, leading to the loss of neurons and synapses. Most often, the brain structures associated with memory (such as the hippocampus) are damaged first. As the disease progresses, language, behaviour and speech are affected too. The death of neurons in the cortex (the outer layer of the brain) leads to the loss of long-term memories. Interestingly, a person's ability to sing or play a musical instrument are stored deep within the brain, and these connections appear to be retained for longer.

In rarer cases of Alzheimer's disease, people may not experience difficulties with their memory but instead with their sight. This form of Alzheimer's is called Posterior Cortical Atrophy (PCA) and causes degeneration of the cells at the back of the cortex. The occipital lobe, the visual processing centre of the brain, is located here, so vision is affected. Some PCA sufferers may also experience difficulties with spatial awareness if parts of the parietal lobes are affected. *Discworld* author Terry Pratchett revealed he was diagnosed with PCA in 2007.

There are some medications that can help to manage symptoms or slow the progression of Alzheimer's, but there is currently no cure. Current research is focussed on developing new drugs or techniques that can stop the disease and/or reverse its effects.

> *"In Alzheimer's, abnormal protein plaques build up in and around neurons"*



Amyloid plaques (orange) are a characteristic feature of Alzheimer's disease. The proteins destroy the connections between neurons

Narcolepsy can cause people to fall asleep without warning at inappropriate times

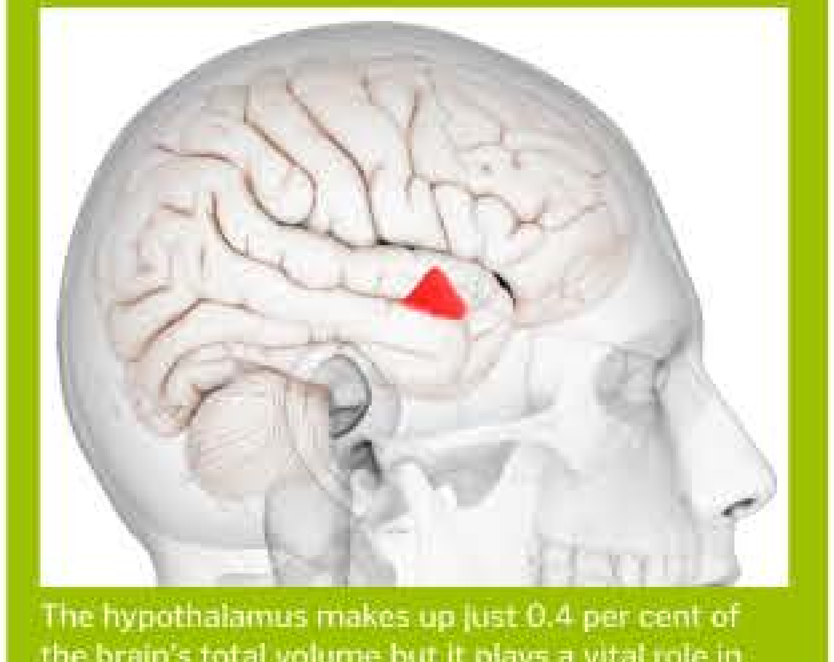
Narcolepsy

Sufferers of this condition randomly and uncontrollably fall asleep

Narcolepsy is an uncommon, long-term brain disorder affecting roughly 30,000 people in the UK. It affects the brain's ability to regulate sleep-wake cycles, causing sufferers to suddenly fall asleep.

The body's sleep-wake cycle is normally controlled by the hypothalamus (an almond-sized region found deep within the brain) that produces a chemical called hypocretin. This chemical normally helps to regulate wakefulness, but most narcoleptics do not seem to produce it in significant levels. Scientists think that the immune system mistakenly attacks the cells that produce hypocretin. However, this isn't the cause for all cases of narcolepsy – some may be triggered by stress or an infection.

Although there is no cure for narcolepsy, there are medicines that can control some of the symptoms. For some sufferers, lifestyle changes may also help. Current studies aim to find the definitive cause of narcolepsy and new ways to treat it.



The hypothalamus makes up just 0.4 per cent of the brain's total volume but it plays a vital role in the functions of the autonomic nervous system

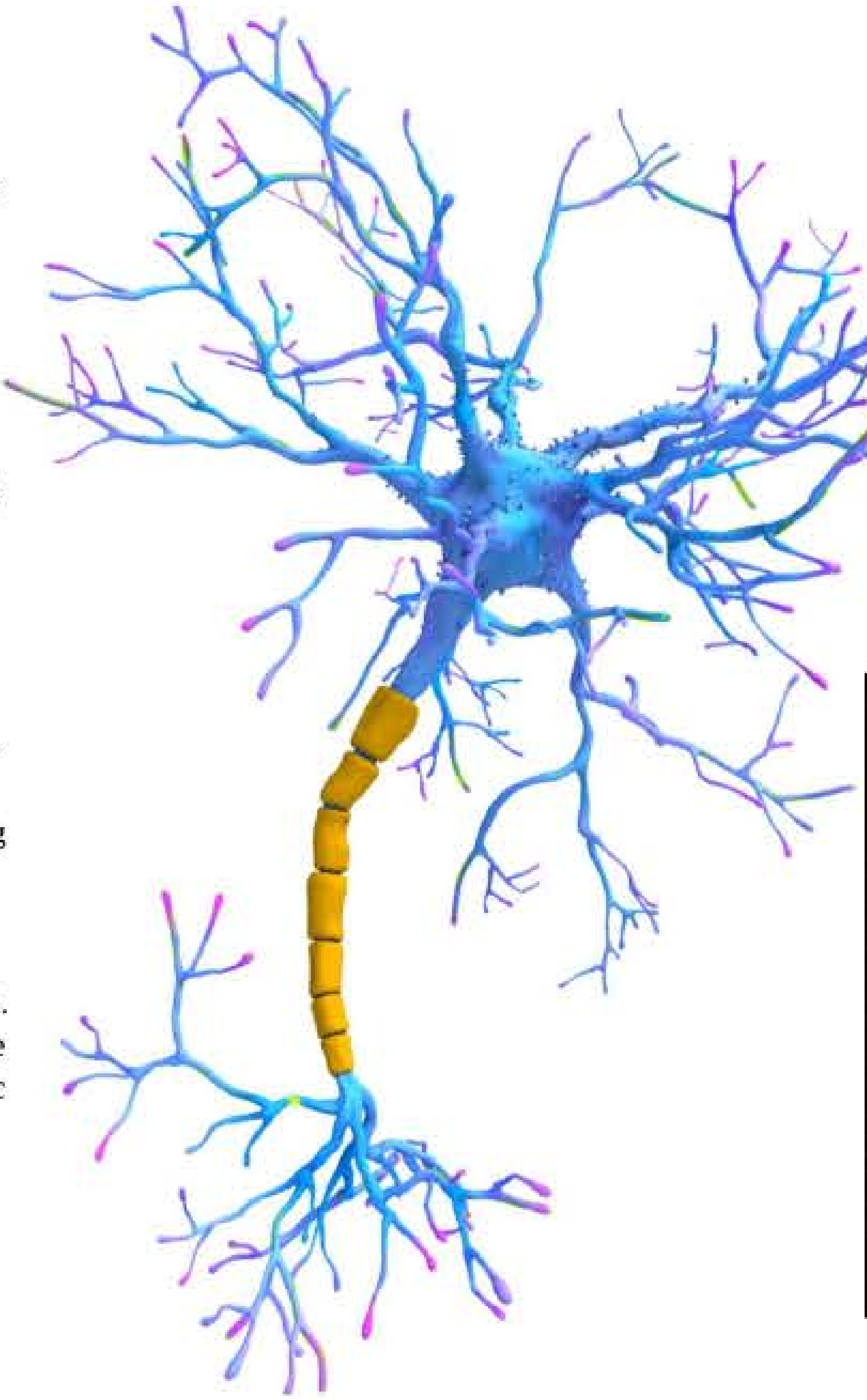
Multiple sclerosis

MS affects the vital 'insulation' around nerves

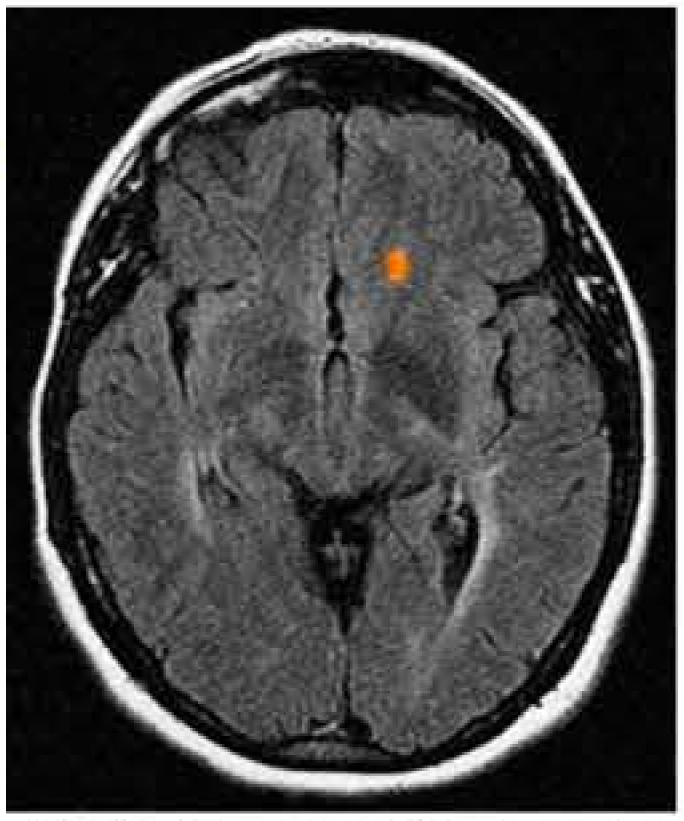
Multiple sclerosis (MS) is a life-long condition that affects nerves in the brain and spinal cord, causing a wide range of symptoms including problems with movement, vision and balance, but one of the most common is fatigue.

Each axon, also known as a nerve fibre, is a part of a neuron that carries electrically charged impulses. The axon is surrounded by myelin, a fatty substance that – like insulation around an electrical wire – allows the neuron to send messages around the body more efficiently. In MS, the immune system mistakenly identifies myelin as a foreign substance and attacks it. The damaged myelin disrupts the transfer of nerve signals by either slowing them down or stopping them completely. During an attack – when a person is displaying the symptoms of MS – the myelin is destroyed and then scarred, preventing effective brain-body communication.

There is currently no cure for MS, but there are treatments. Medications are able to treat specific symptoms, and disease-modifying drugs can help to reduce the incidences and severity of relapses. Research is ongoing and hopes to understand how MS is triggered, whether it can be cured and whether the damage it causes can be repaired.



In MS, the myelin sheath (yellow) becomes damaged, which reduces the efficiency of the neuron's ability to transfer messages



MS patients experience different symptoms depending on which nerves are affected

Motor neuron diseases

Motor neurons tell your muscles what to do, but these conditions cause them to become damaged

Motor neuron diseases (MND) is the name given to a group of conditions that destroy the body's motor neurons – the specialised nerve cells that are responsible for controlling the movement of our muscles via the central and peripheral nervous systems. From gripping a glass and waving your hand to walking, breathing and swallowing, the motor system allows us to make the movements that we depend upon every day. MND are rare, progressive conditions that affect roughly two in every 100,000 people in the UK.

There are two types of motor neurons: upper motor neurons (in the brain) and lower motor neurons (in the brain stem and spinal cord). Electrical messages are transmitted from the upper motor neurons to the muscles in the arms, legs, tongue, face, torso and more via the lower motor neurons. However, if the signals between the lower motor neurons and the muscles are damaged, the muscles stop working, gradually weakening and wasting away. Eventually the brain is unable to initiate and make these voluntary movements.

There are four main types of MND, and each type affects each person differently. The most common form is called amyotrophic lateral sclerosis (ALS) and affects the muscles in the legs, arms and face. Renowned physicist Professor Stephen Hawking was diagnosed with ALS at the age of just 21.

MND are ultimately fatal, but some symptoms can be managed with medication. Research into MND is ongoing, with a view to developing new, more effective treatments.

Healthy motor neurons carry signals between the brain and the muscles, but in a person with MND these nerves die, causing the muscles to weaken

Stroke

When the brain's blood supply is disrupted, it's a matter of life or death

A stroke is a medical emergency and occurs when the blood supply to part of the brain is disrupted, generally due to a blood clot or a bleed – similar to a heart attack. Consequently, brain cells do not get enough oxygen or nutrients, resulting in neuron damage or death. This affects a person's ability to speak, move, see and think, so it's vitally important that the blood supply is restored quickly to the brain. The effects of a stroke are dependent on what part of the brain was affected and how quickly it was treated. It's a leading cause of death and disability worldwide; approximately every two seconds someone suffers a stroke.

There are two main types of stroke: ischaemic and haemorrhagic. Ischaemic strokes account for around 85 per cent of cases, and these occur when a blockage prevents proper blood flow around the brain – typically a blood clot. Haemorrhagic strokes occur due to a burst blood vessel, and these account for the remaining 15 per cent of cases.

A related condition called a transient ischemic attack (TIA), also known as a 'mini-stroke', occurs when there is a brief interruption to the blood supply to the brain; the blockage moves or dissolves so symptoms only last for up to 24 hours. Nevertheless, these mini-strokes are still a medical emergency.

Strokes can be treated with medicines that help to dissolve blood clots as well as drugs to prevent further strokes, or surgery to remove a blood clot or repair blood vessels.

If you suspect that someone is having a stroke, it is important to get help **FAST**:

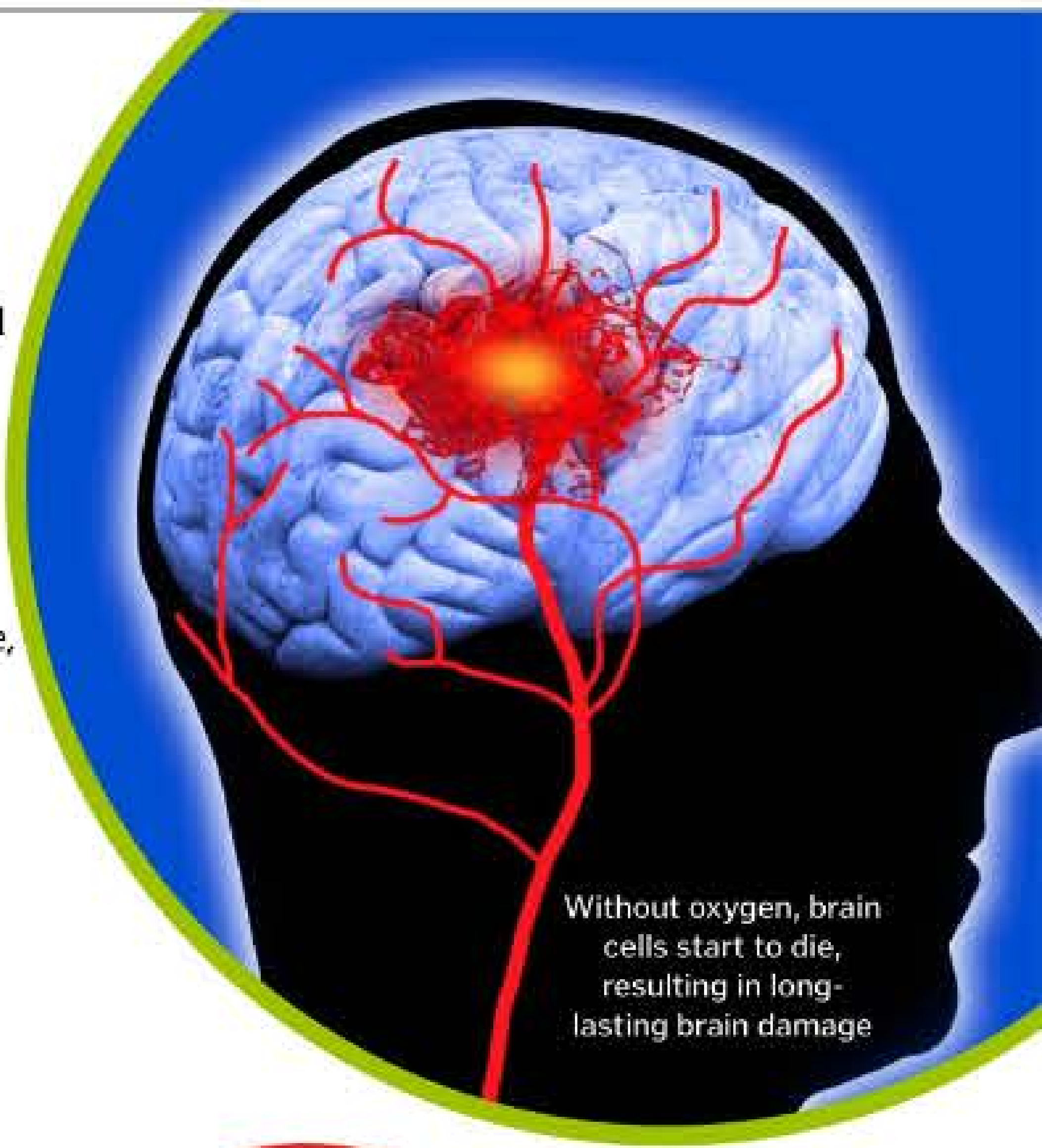
FACE Is their face drooping? Can they smile?

ARMS Is there weakness? Can they lift up both arms?

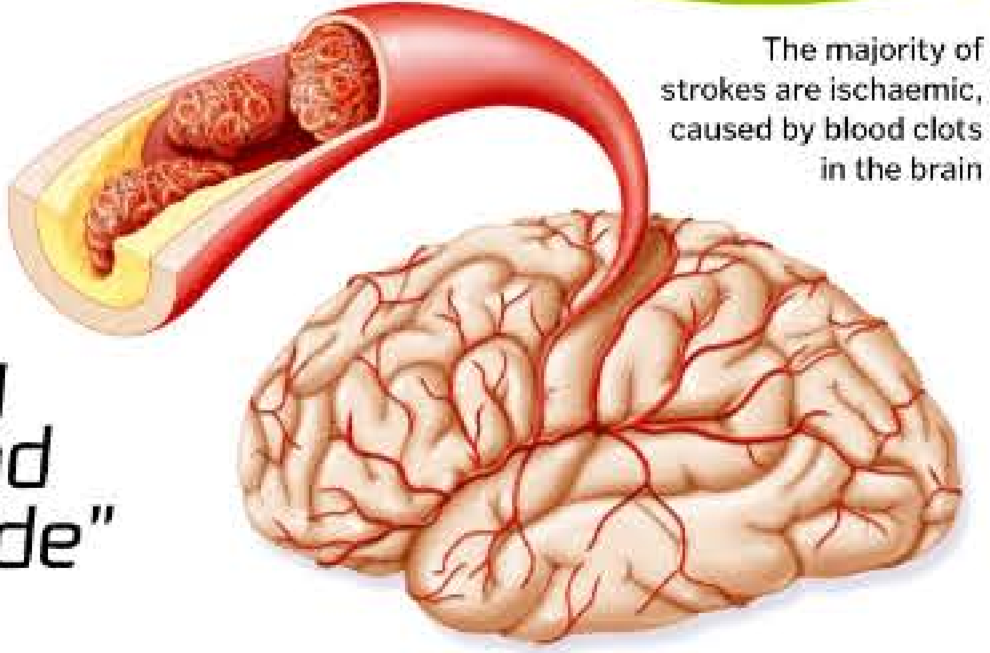
SPEECH Is their speech slurred or garbled?

TIME Time to act. Call the emergency services.

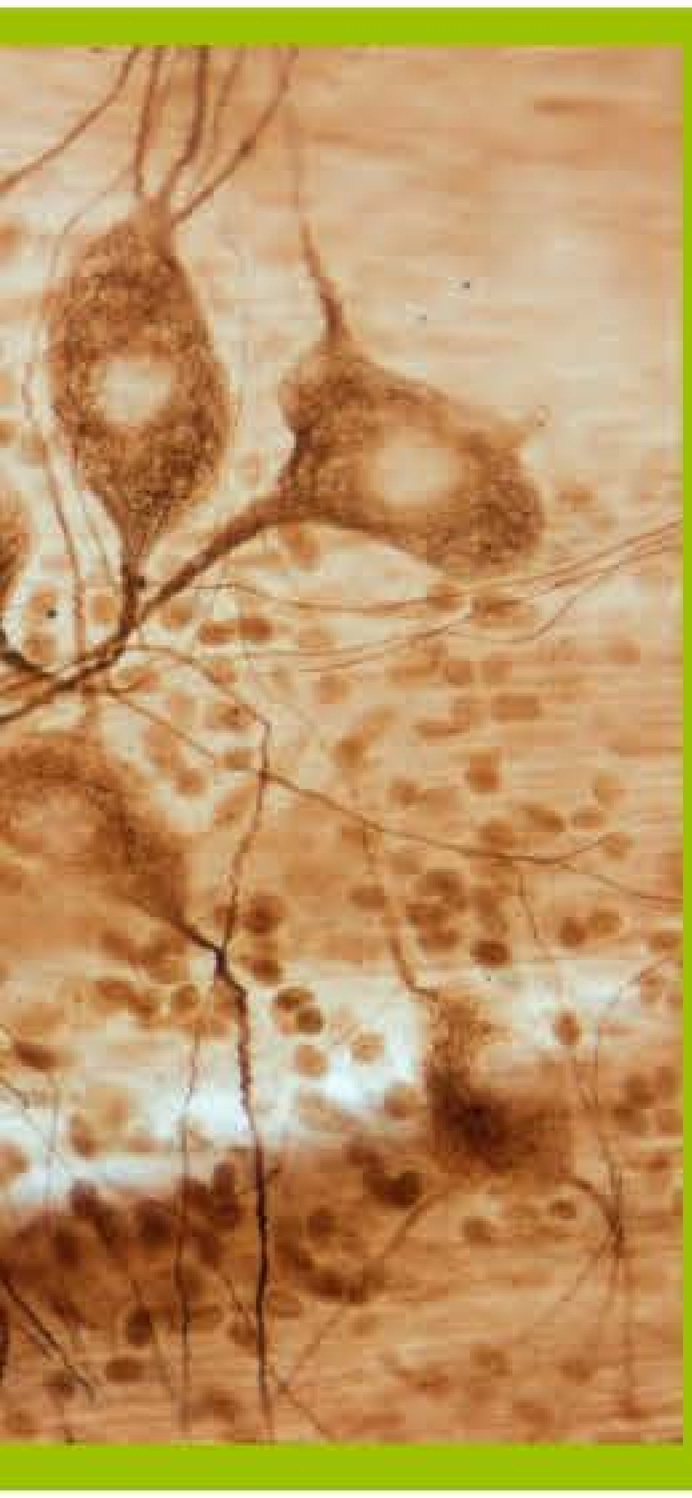
> "Stroke is a leading cause of death and disability worldwide"

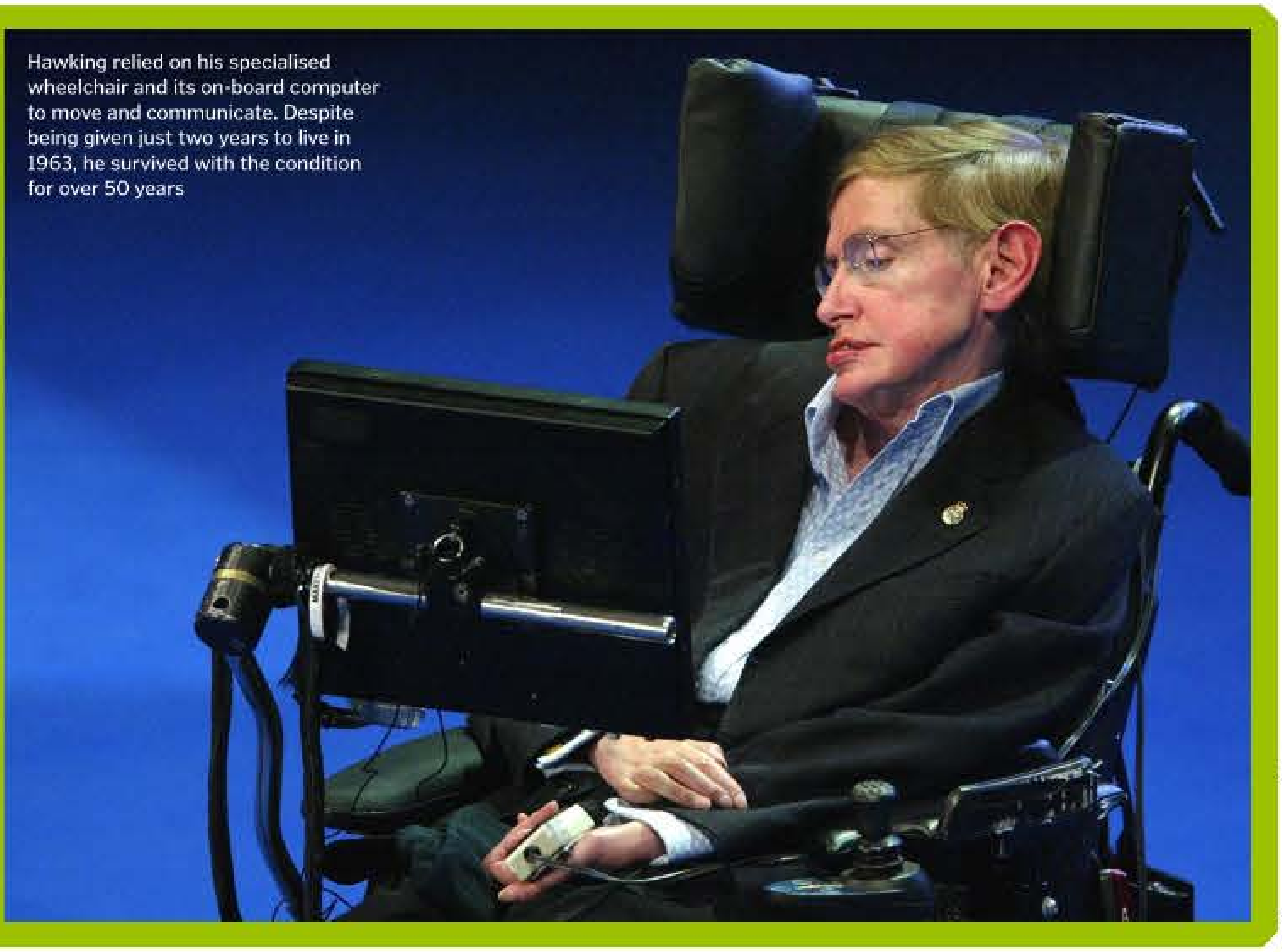


Without oxygen, brain cells start to die, resulting in long-lasting brain damage



The majority of strokes are ischaemic, caused by blood clots in the brain





Hawking relied on his specialised wheelchair and its on-board computer to move and communicate. Despite being given just two years to live in 1963, he survived with the condition for over 50 years

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10 UNETHICAL PSYCHOLOGY EXPERIMENTS

Meet the researchers who cast aside morality to uncover secrets of the human mind

Despite our immense intelligence, humans are irrational, confusing creatures. Our emotions and behaviours are sometimes hard to predict and even harder to justify, making the science of psychology essential for truly understanding our incredible minds. Like in any science, psychologists have long used controlled experiments to test their hypotheses, but their test subjects aren't viruses or bacteria – they're us.

Today if you were to enter a university psychology study you'd likely be met by a young, excited graduate student with a detailed disclosure form. They'd take you through the process and explicitly warn of any discomfort you may feel, which at its harshest would be minimal. But studies weren't always this way.

A researcher's pursuit for knowledge – and sometimes their pursuit for personal glory – can drive them to conduct studies of an insidious nature on human test subjects, and in past decades there has been little legislation to keep these experimenters in check.

Throughout this feature, we'll reveal a government-funded study that secretly spiked civilians with psychoactive drugs, uncover several experiments that aimed to traumatise young children, and explore others that caused volunteers considerable distress in a bid to reveal some unsettling truths about the human psyche. So strap into your harnesses and read on, and see if you can discover when a human being simply becomes a datum to the experimenter's eye.

Little Albert study

Pavlov's dogs were conditioned on treats; baby Albert was conditioned on fear

Albert's mother received the paltry fee of $1 for her infant son's participation in the experiment

Experimenting on unwilling or unaware test subjects is always considered dubious, but to experiment on an innocent baby is arguably the worst of the lot. But that is exactly what John Watson decided to with little baby Albert, who found himself as Watson's subject at just nine months old.

The experiment started off innocuously enough. Albert was introduced to an adorable rabbit, an excitable monkey, a friendly dog and a curious small white rat. He appeared engaged and interested in all them – especially the scurrying rat – and even cupped the dog's paws with both of his hands. He showed no signs of fear, which was exactly what Watson wanted.

As the months progressed, Watson began conditioning Albert to fear the animals. Every time one of them would get close to the baby he would clatter on a metal bar and frighten him. This caused Albert distress and he soon learned to associate the animals with his fear and would either cry or try to crawl away when in their presence, even without the bar being struck.

But it appeared that this torture was not enough for the researcher. Over time the conditioning affect faded, and Albert would grow more settled in the presence of the animals. This encouraged Watson to re-introduce the clanging of the bar, re-igniting Albert's fear to prove that his conditioning theory could be used repeatedly.

Human experimentation, sometimes harmless and other times not, has been a cornerstone of experimental psychology from its inception

The monster study

An attempt to cause a life-long affliction in children to prove one theory

Wendell Johnson was a prominent speech pathologist in the 1930s. For those who knew him this was no surprise, as it was a profession he had a personal stake in – he'd suffered with a speech impediment since childhood. He was adamant that his parent's actions were to blame for his disorder. He believed that highlighting a child's speaking difficulties made them overly self-conscious of their words, which over time would develop into a life-long impediment. To prove his theory, in 1938 Johnson recruited a master's student, Mary Tudor, to experiment on unwilling orphan children.

During her sessions, Tudor separated the children into two groups, both containing children with pre-diagnosed speaking difficulties and able speakers. One group received only positive input regarding their speech, and the other received chastising and negative reinforcement to make them self-conscious when speaking. The study hoped to find that those with speaking difficulties would improve in the positive group, while impediments would worsen in the other.

The experimental data supported neither hypothesis, but the legacy of the study was the emotional trauma suffered by the children in the negative group. Some withdrew and became incredibly quiet and self-conscious individuals, causing Tudor's peers to dub her thesis as "the monster study". Johnson himself committed another ethically dubious act by not discussing the work upon its completion, deciding instead to ignore evidence that clearly contradicted his

© Cloy Kent

Wendell Johnson was one of the most prominent speech pathologists of his day

The Robber's Cave experiment

The boys became so antagonistic that burning their rival's flag became a proud accomplishment

A scheme that manipulated children into tribal warfare

Any fan of a sports team will tell you that it's easy to become competitive and antagonistic towards members of rival groups. Psychologist Muzafer Sherif described these tribal thoughts as part of the realistic conflict theory, which states that different factions will inevitably fall into competition and animosity when battling for limited resources.

In his most famous experiment, Sherif designed an experiment involving unsuspecting youths at camp. After arriving at Robber's Cave State Park, Oklahoma, US, a cohort of 12-year-old boys was divided into two groups. During the first week the groups were kept unaware of each other's existence, and the boys bonded with their peers and shared in activities such as hiking and swimming. However, this tranquillity was not to last.

Over the following days, the groups were introduced and forced to compete. They would race to pitch tents, wrestle in tugs of war and play baseball, with the winners receiving a prize. To increase the tension, experimenters would also declare that the contests were extremely close, and feelings of deep prejudice soon formed. One group even went so far as to destroy their rival's flag, inspiring an act of vengeance where the flag-destroyer's cabin was ransacked. Soon fist-fights broke out, and the researchers had to pull the boys apart.

MK Ultra ran for around two decades and administered illegal drugs to many unsuspecting civilians

Homosexuals were forced to suffer great distress and discomfort during aversion therapy

Aversion therapy

A brutal treatment plan that preyed on desperate, persecuted and coerced individuals

The time when homosexuality was considered a disease is still well within living memory for many. A slew of governments were eager to help 'cure' such an affliction and established centres reliant on unproven yet widely used procedures. The conscript military of apartheid South Africa was home to one of the most nefarious treatment centres for homosexuals.

The main practice to convert patients to heterosexuality was aversion therapy, which involved showing the patient erotic images or videos of a homosexual nature before inflicting them with pain or discomfort. In South Africa electrical shocks were applied under the arms, but other centres would give the patient sickness pills so they'd vomit as they saw the images.

The hope was that the patient would begin to apply feelings of pain and nausea to those of sexual thoughts about members of their own sex, thus driving them into heterosexuality, but success was rare.

Project MK Ultra

The drug-induced investigation into mind control funded by the US Treasury

In the 1950s, the United States had grown concerned over reports that China and the Soviet Union were developing mind-control technologies to use on their undercover operatives. Not to be outdone, the US started administering psychoactive drugs as a gateway to mind control, sometimes on willing subjects and sometimes on unsuspecting victims.

Part of the MK Ultra's operations was one Project Midnight Climax, in which prostitutes under the employ of the CIA lured in unsuspecting men and sneakily drugged them with LSD, a psychoactive agent that causes hallucinations. The agents, secretly watching from behind a mirror, would then observe the effects it had on the men's minds.

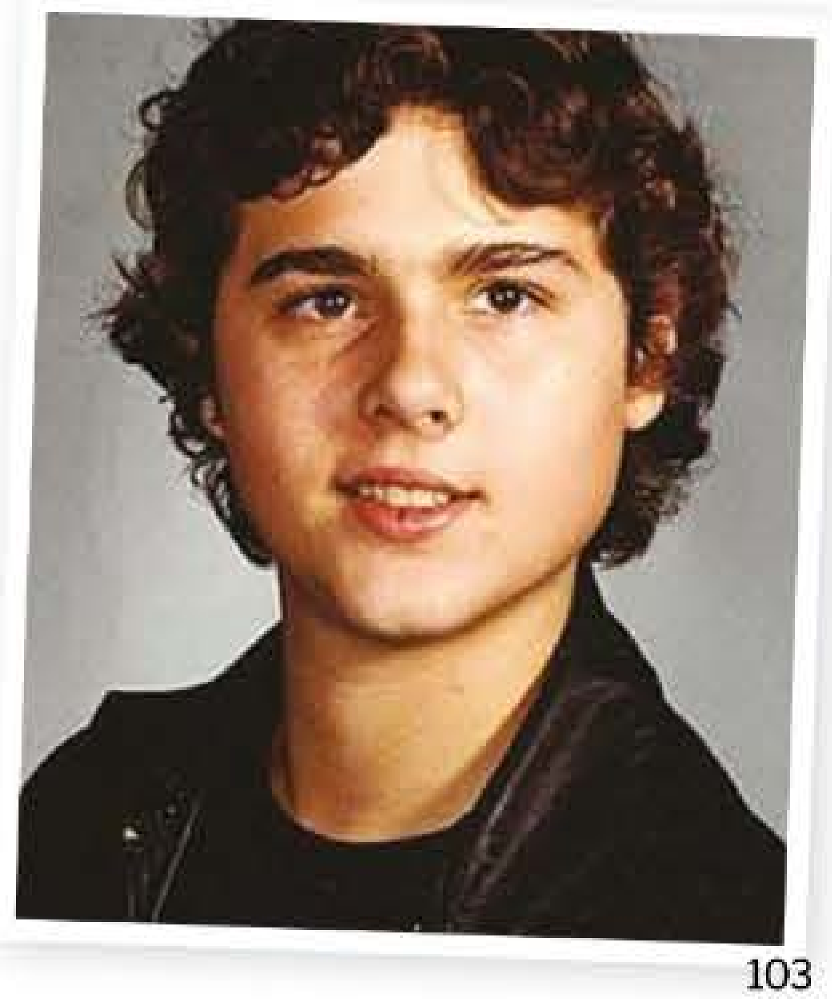
Although much of the documentation of MK Ultra has been lost or destroyed, we know that it directly caused at least one death. A CIA scientist named Frank Olson consumed a drink secretly spiked with LSD and several days later fell to his death from a hotel window. President Gerald Ford finally ended the futile and sinister project in 1976 as he moved to limit the powers of intelligence agencies operating in the US.

The nature vs nurture case study

One vulnerable family afforded an ambitious researcher his ideal subject to test gender roles

At just eight months old, twins Bruce and Brian Reimer were admitted to hospital for a routine circumcision operation. However, the surgical equipment malfunctioned during Bruce's surgery and the child unfortunately lost most of his penis. Bruce's parents were dismayed until they saw Dr John Money on television. Money believed that gender roles were solely determined by how children were raised, and so together the Reimers decided that the young child would become Brenda. She was Money's ideal experiment.

Money published the gender-switching case study when Brenda was nine years old and claimed it was a massive success, but privately the child was having difficulty mixing with other girls. Her depression only worsened as she reached puberty and at 13 her parents took the step to tell her the truth. Brenda swiftly decided to become David, and would later have a penis constructed, get married and act as a step-father to his wife's three children. However, a deeply disturbing childhood appeared to have deep roots, as after separating from his wife and losing his job David took his own life aged just 38.



David Reimer underwent two gender switches throughout his life, although only one was his decision

The murder of Kitty Genovese brought national attention to the bystander apathy effect

The bystander apathy test

Sometimes the results of a study are just as dark as the experiment itself

On 13 March 1964, a young woman named Kitty Genovese was stabbed to death as she walked home from work in Queens, New York. The brutal murder was committed in a populous neighbourhood and Kitty screamed for help, but to no avail. It was reported that 37 people heard her cries, but not one came to her rescue in time. Psychologists described this phenomenon as the bystander effect, a trait that means we're more likely to do nothing when part of a group.

Social psychologists John Darley and Bibb Latané decided to conduct an experiment in the wake of this heinous crime to test the extent of the bystander effect. They invited participants into a study under the guise that the goal was to discuss their college lives. The participants were physically isolated from one another but would be placed in groups of various sizes to discuss the problem via audio. Unbeknownst to the test subjects, every member of the group aside from them was an actor, one of which would feign a severe epileptic fit during the test. Disturbingly, the researchers observed the bystander effect in full force. If the participant was in a one-on-one group with the suffering actor, they would seek help nearly every time. But when they were part of a group, they would seek help less than one-third of the time, instead leaving the supposed sufferer to their fate.

Milgram shock experiments

Just how far can authority force us to go?

In the wake of World War II, members of the former Nazi Party were put on trial and defended their heinous actions by claiming that they were simply following orders. A little over a decade later one Yale psychologist named Dr Stanley Milgram became increasingly interested in the role of authority and obedience on morally questionable acts, and in July 1961 he began a series of experiments to see just how far obedience could go.

His experiment involved three participants: a 'student', 'teacher' and 'experimenter'. The teacher's role was to ask the student questions based on memory and if he failed to answer correctly to apply an electric shock as punishment. The voltage would be increased incrementally from 15v, clearly labelled as safe, to 300v, clearly labelled as dangerous, to beyond to 450v. If the teacher wavered on delivering the punishment, the authoritarian figure of the experimenter was there to prompt them to continue.

The role of teacher and student was supposedly randomly assigned between two volunteers, but in reality it was rigged to place the genuine volunteer as the teacher and an actor as the student. The shocks themselves were also artificial, but the fake student was told to scream out in pretend agony following a shock. Despite protestations and signs of visible distress from the volunteers who reluctantly electrocuted the student, over half of them delivered what they believed to be a shock of 450v purely because they were under the instruction of a respected authority figure.

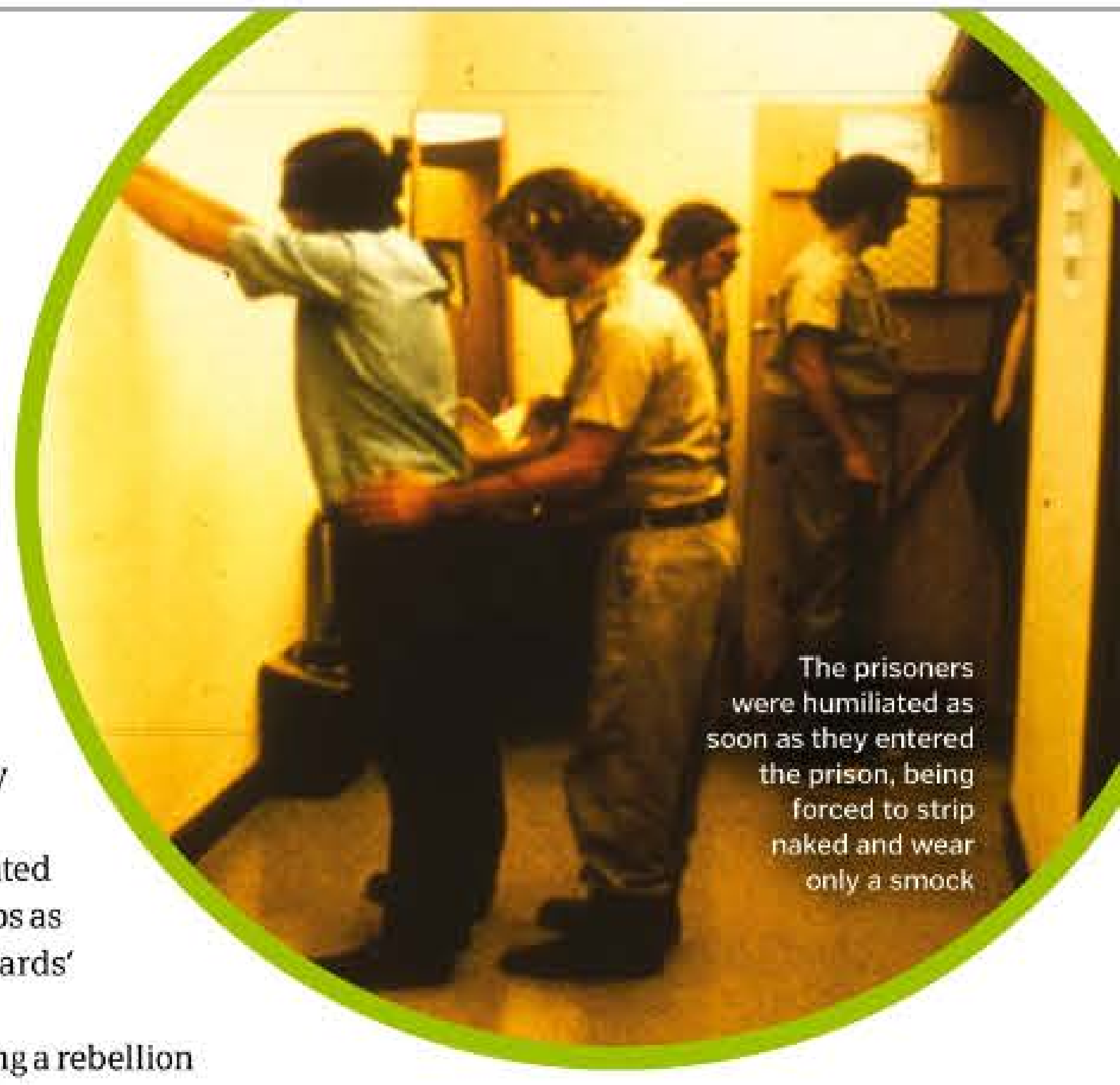
Milgram's work became a landmark study despite the stress it caused participants

The Stanford prison experiment

A meticulously designed study that swiftly devolved into anarchy

Do positions of authority corrupt us? And how easily can our individual identities be stripped away? Questions such as these inspired one of the world's most controversial psychologists, Dr Philip Zimbardo, to build a mock-up prison in the basement of Stanford University's psychology department building and populate it with young innocents. The Stanford Prison Experiment would randomly divide half of the 18 volunteers into guards and the other half into prisoners, and over the following six days it would morph into one of the most absurd studies ever conducted.

At the beginning of the experiment, the 'prisoners' were arrested, stripped of their clothes and possessions and locked behind barred doors. The 'guards' were given a uniform and minimal instructions, save that they were there to keep the prisoners in check. It didn't take long for some of the guards to begin to relish their new roles. They started blowing whistles in the middle of the night and soon escalated to making the prisoners do push-ups as punishment – sometimes with a guards' boot planted on their back.



The prisoners were humiliated as soon as they entered the prison, being forced to strip naked and wear only a smock

The prisoners lashed back, staging a rebellion on the second day by piling their mattresses against the bars and refusing to leave. But once they had been subdued, the guards became worse: they removed the prisoners' mattresses, made them urinate and defecate in buckets and then locked them in 'the hole' – a small, dark cleaning closet that was too small to sit in – for hours at a time.

Understandably, several of the prisoners suffered emotional breakdowns and had to be removed from the study, which was brought to a close after just six days. It was scheduled to last two weeks, but after Zimbardo's girlfriend witnessed the experiment, she spoke out against its inhumanity. According to Zimbardo, 50 other witnesses had viewed the experiment prior to her and none had raised any objections.

> "Understandably, several of the prisoners suffered emotional breakdowns and had to be removed from the study"

The facial expressions experiment

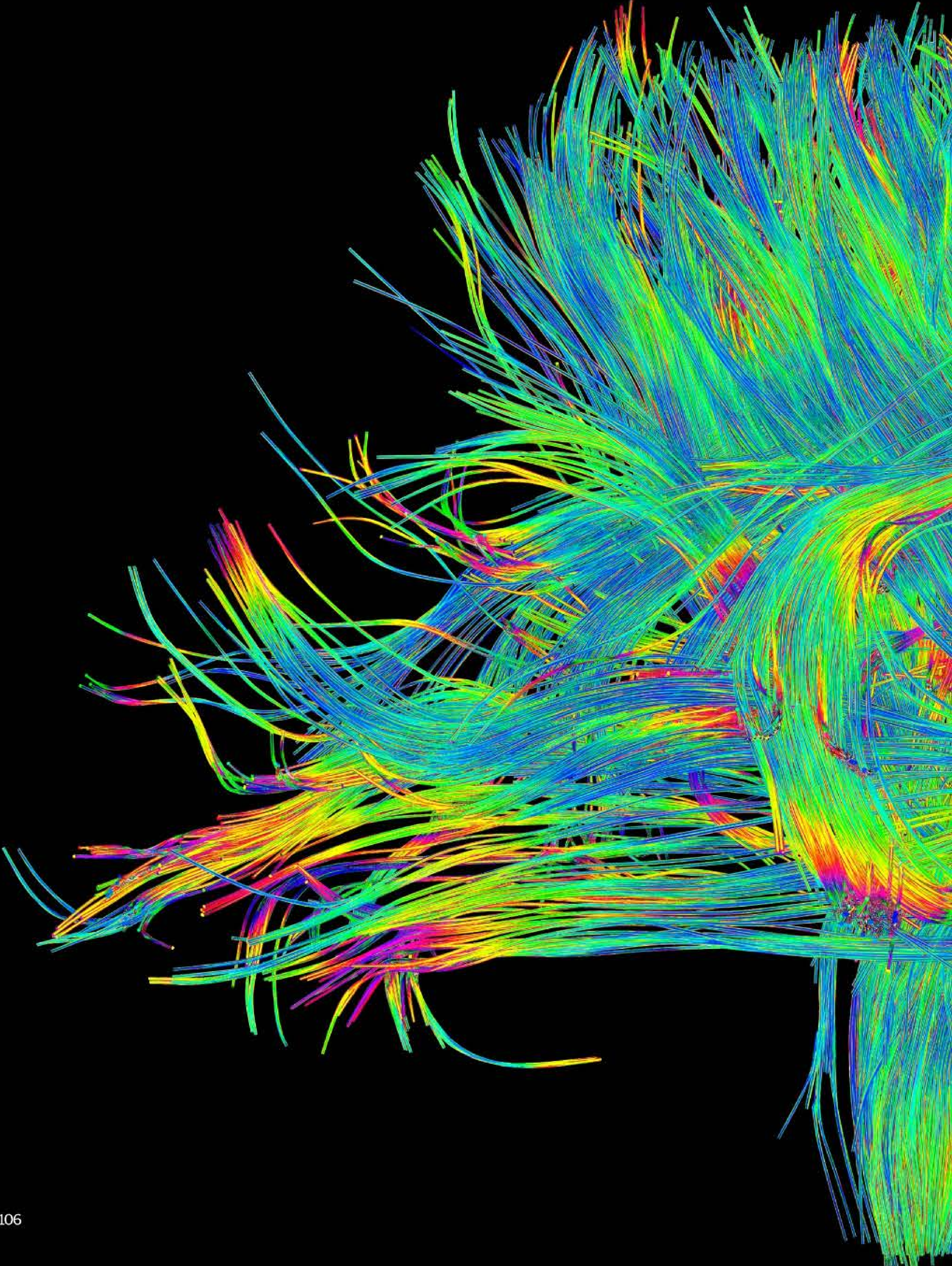
Do we all look the same when massaging a box of frogs?

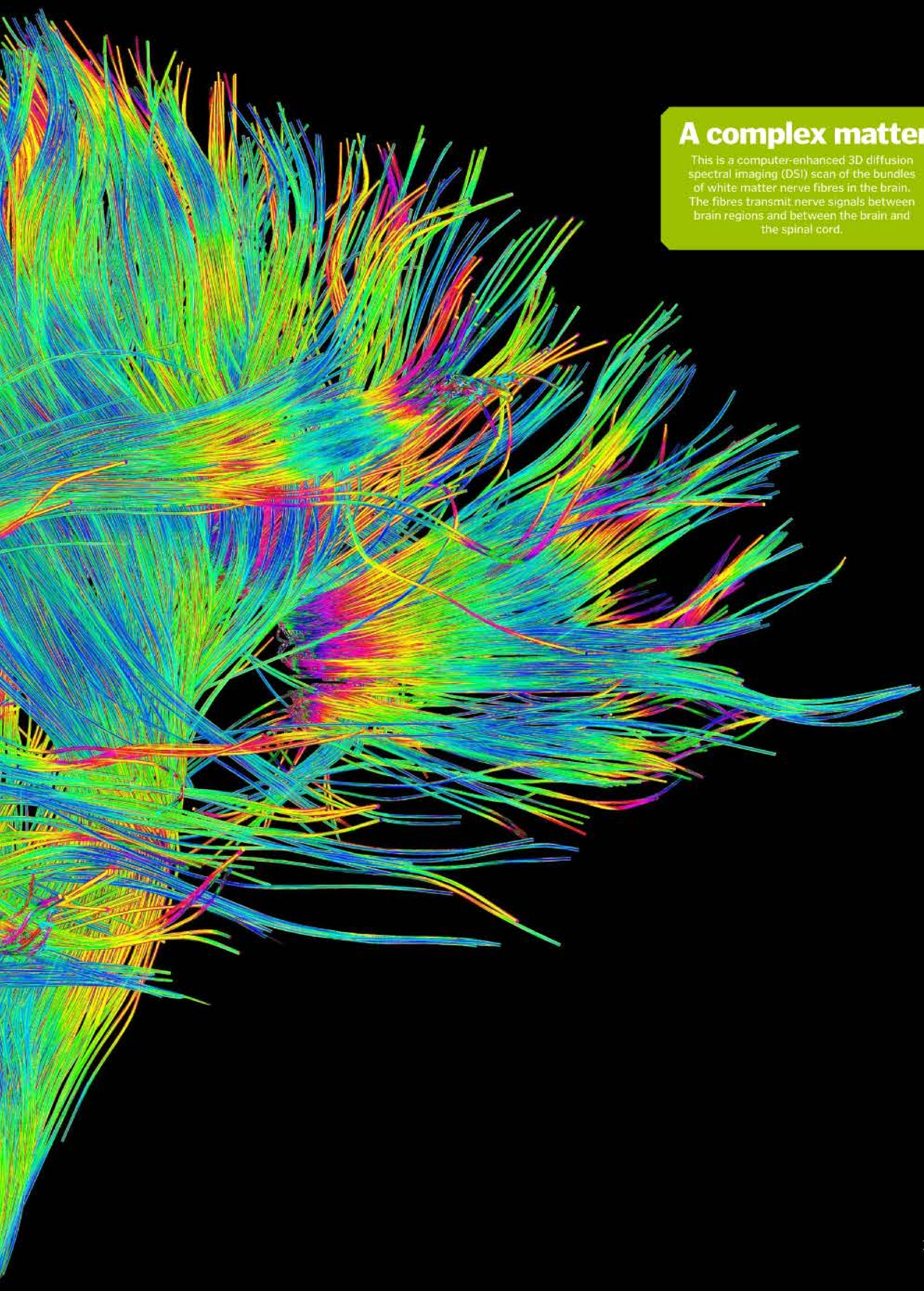
In the 1920s, psychologist Carney Landis was interested in the expression of emotion. He wondered if, innately, humans all pull their muscles in similar ways when they smile and grimace. Landis planned to illicit emotional responses in his patients through tangible cues and document their facial muscle movement to see if a common pattern existed. His belief was that simply asking someone to imitate an emotional expression would not be the same as a genuine reaction, and so his cues were designed to evoke them organically.

He electrocuted his subjects to photograph the expression of pain and told them to place their hand in a bucket of frogs to witness their disgust. At the most extreme end, he instructed them to behead a live rat with no training and minimal instruction. One-third of the participants agreed willingly, but for those who refused he simply decapitated the rat in front of them and made them watch.

Despite Landis going the extra mile to capture the authentic emotional responses, in the end he couldn't find any common pattern of facial expressions in his results.

Carney Landis went to extraordinary lengths to goad his test subjects into expressing particular emotions





A complex matter

This is a computer-enhanced 3D diffusion spectral imaging (DSI) scan of the bundles of white matter nerve fibres in the brain. The fibres transmit nerve signals between brain regions and between the brain and the spinal cord.

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THE PSYCHOPATH: MAD OR BAD?

It's estimated that one in every 100 people is a psychopath. Do you know how to spot one?

The cold, callous and enigmatic psychopath is a mainstay of popular culture; appearing on page, stage and screen, it has thrilled and appalled audiences from biblical times to the modern day. Indeed, the term 'psychopath' has become so embedded in the popular imagination as to become cultural shorthand for a very particular kind of evil. The label is typically applied to people exhibiting socially deviant behaviours, often including violence, plus low inhibition and a lack of affect. But what does it mean to be called psychopathic? And what can be done to treat the condition?

Psychopathy is a personality disorder – the first to be identified, in fact – and scientists have argued for decades over the precise parameters of the syndrome. The word itself literally means 'mental illness' (from the Greek *psykhe*, meaning 'mind', and *pathos*, which means 'suffering'). This association with madness has coloured popular conceptions of psychopathy: the term typically conjures images of maniacs and murderers with mad, staring eyes. However, psychopaths are not actually insane – they don't suffer from delusions or hallucinations and there are no psychotic breaks or cyclical bouts of mental ill-health. Instead, the psychopath is rational and sane and fully in control of the choices they make. This makes the crimes of people like Ted Bundy and Fred West even more terrifying; they weren't victims of a terrible illness, divorced from reality; they chose to commit murder. That said, most law-abiding citizens are sickened by the idea of committing such horrific crimes; surely, the lament goes, 'one would have to be crazy to do that'?

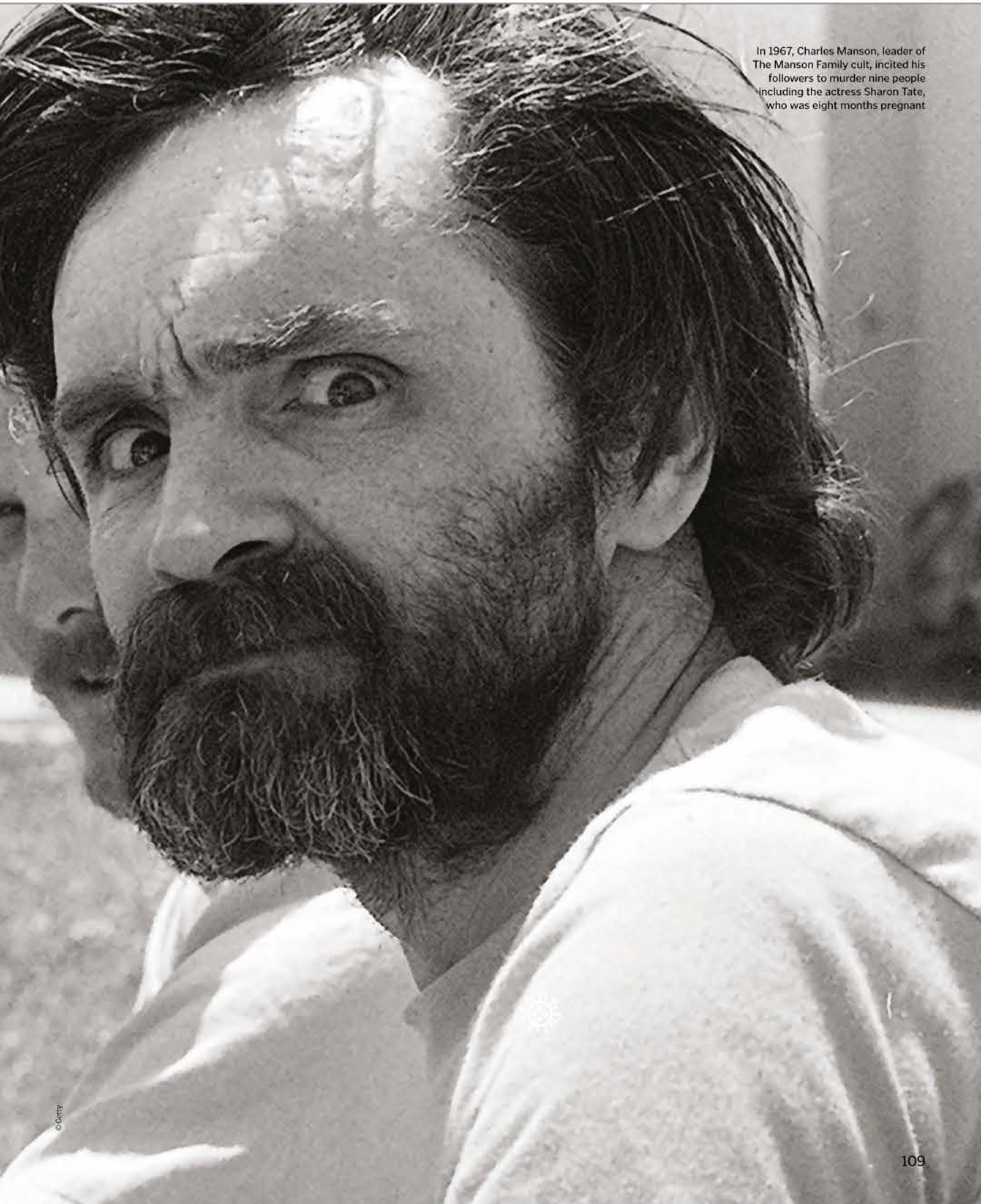
> "The term typically conjures images of maniacs and murderers"

The debate as to whether the psychopath is 'mad or bad' continues to rage, and in large part the argument rests on the legal conception of insanity. Insanity determines whether a person can be held responsible in law for their actions, and experts are split as to the culpability of the psychopath. Their control and rationality suggest that they should be held responsible for their transgressions, yet they behave as they do because they were born a certain way. If psychopathy is a biological disorder, can a person presenting with the syndrome really be deemed culpable for the crimes they commit? It's a thorny issue, but what is clear is that psychopathy is largely untreatable; there is no cure or therapy that has been shown to be effective. While patients present as 'sane', clinical tests reveal that their brains work very differently to those of the broader population.

THE 'REPTILIAN BRAIN' OF THE 'SNAKES IN SUITS'

The forensic psychiatrist J Reid Meloy has suggested that the "predatory aggression [that] is the hallmark of the psychopathic individual" indicates that they are functioning from the "reptilian brain". According to the theory of the triune brain, which was developed by American neuroscientist Paul MacLean, the reptilian brain is primarily concerned with physical survival. It governs vital functions such as heart rate, body temperature and breathing and is responsible for our fight or flight mechanism.

The reptilian brain is further linked to territoriality and ritual and has a tendency towards rigidity and compulsive behaviours.



In 1967, Charles Manson, leader of The Manson Family cult, incited his followers to murder nine people including the actress Sharon Tate, who was eight months pregnant

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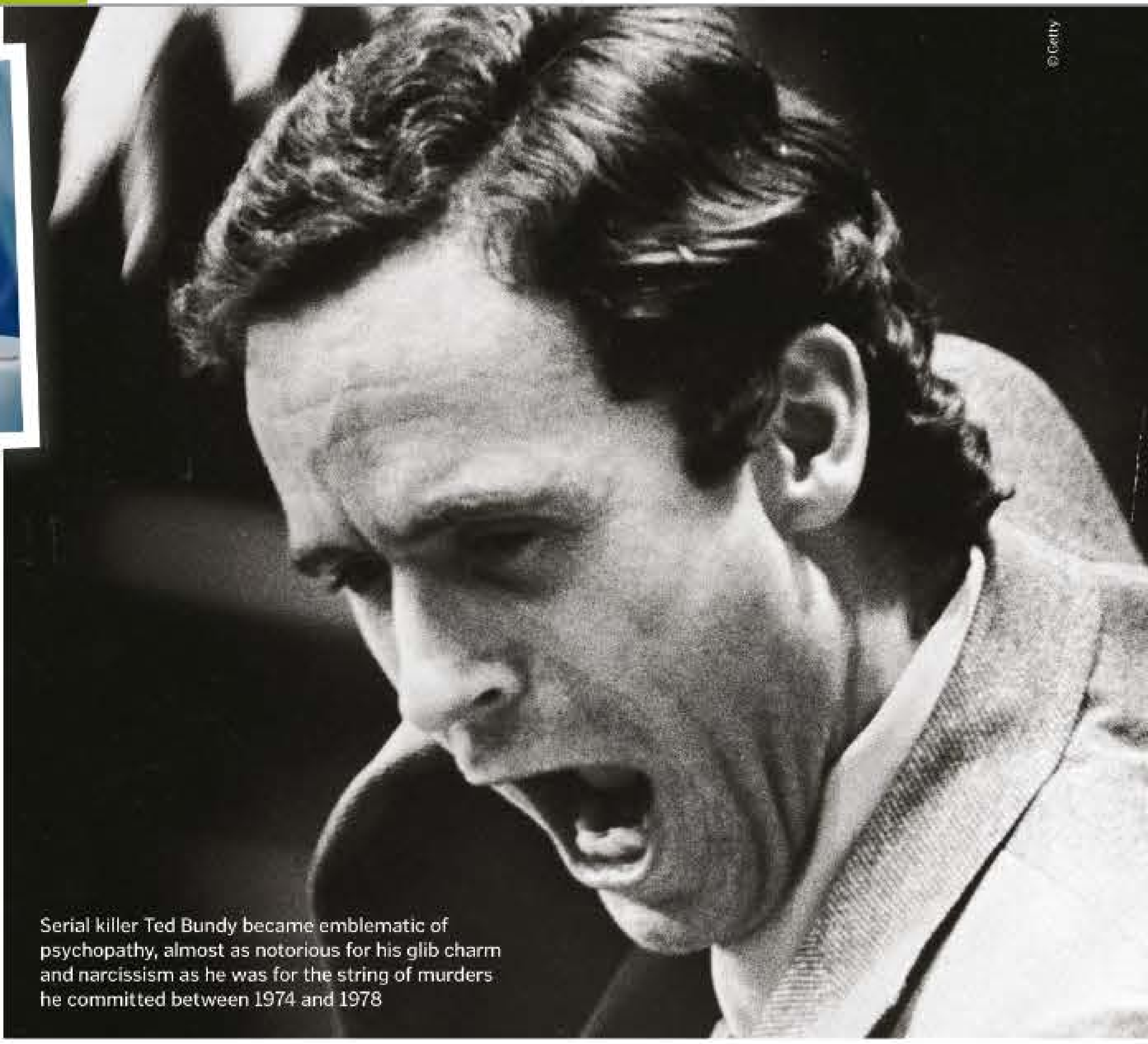
Psychopaths can make excellent surgeons, as their lack of empathy means their clinical judgement is unlikely to be clouded by emotion

Crucially, it also plays a significant role in establishing social dominance. Some clinicians believe that, in the psychopathic subject, this primitive brain takes precedence over the higher-functioning neocortex (human brain), which gives us reason, and the limbic system, or mammalian brain, which is responsible for emotion. Reptiles do not have a limbic system and, like the psychopath, therefore have no capacity for emotion or empathy.

This lack of emotion is beneficial to the psychopath in many ways, allowing them to rationalise their behaviour and deny culpability for damaging actions. This is useful for the criminal psychopath who can continue to satisfy their basest urges without fear of being crippled by guilt or remorse. It's also useful for the other type of psychopath – the law abiding high-achiever, who can often be found operating at the highest levels of society.

Researchers have estimated that around one per cent of the population is psychopathic. In a city with 8 million inhabitants that could amount to around 80,000 psychopaths, although Dr Robert Hare, a leading expert in psychopathy, has suggested that in New York the figure might be closer to 100,000. At any one time, psychopaths make up 15 to 20 per cent of the prison population, and they also account for at least 70 per cent of all violent repeat offenders as well as a significant majority of serial killers.

However, most psychopaths won't offend and many of them occupy high-ranking professional roles as surgeons, CEOs, financiers, lawyers, politicians and police officers. Whether you are the leader of the free world, a world-class athlete or a general in the army, the ability to make judgements unclouded by emotion or trample over others to achieve your broader goals is a distinct advantage. A conservative estimate has put the number of psychopaths working at the stock exchange at four per cent, although Hare has suggested that it could be as high as ten per cent. He explains, "Psychopaths are social predators, and like all predators, they are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Serial killer Ted Bundy became emblematic of psychopathy, almost as notorious for his glib charm and narcissism as he was for the string of murders he committed between 1974 and 1978

Would you pass the Psychopath Test?

This pioneering test helps to strip back the carefully cultivated, socially acceptable behaviours that so often mask the disorder

© Stephen McCall

Dr Robert Hare, originator of the PCL-R and one of the world's leading authorities on psychopathy

Diagnosis of psychopathy is often made via the Hare Psychopathy Checklist-Revised, or PCL-R, a criterion-based clinical rating system that measures deviant behaviours and personality traits. Introduced by Canadian forensic psychologist Dr Robert Hare in 1991, the rating scale is applied alongside a structured interview and case history information. This allows the clinician administering the test to build up a detailed picture of the individual and their offending behaviour.

The PCL-R measures the subject's ability to feel empathy for others and also takes into account characteristics such as poor behavioural controls and a need for stimulation, which can lead to criminal behaviour. According to Hare, psychopaths typically exhibit the following traits:

EMOTIONAL/INTERPERSONAL	SOCIAL DEVIANCE
Glib and superficial	**Impulsive**
Egocentric and grandiose	**Poor behaviour controls**
Lack of remorse or guilt	**Need for excitement**
Lack of empathy	**Lack of responsibility**
Deceitful and manipulative	**Early behaviour problems**
Shallow emotions	**Adult antisocial behaviour**

Hare's test is successful at identifying not only psychopathic traits but also a psychopath's risk of recidivism, or repeat offending; it is therefore a useful tool within forensic settings. However, diagnosis can only be made by registered clinicians, such as forensic psychologists or psychiatrists, who have access to the formal scoring manual. Do not attempt to diagnose yourself or others on the basis of the criteria listed above. Many people who are not psychopaths will present with symptoms such as glibness, impulsivity or early behavioural issues, but that doesn't mean that they're psychopaths. As Hare points out, "Psychopathy is a syndrome – a cluster of related symptoms."

Only a small percentage of psychopaths are dangerous criminals – many 'successful' ones take high-ranking roles in finance, politics and medicine

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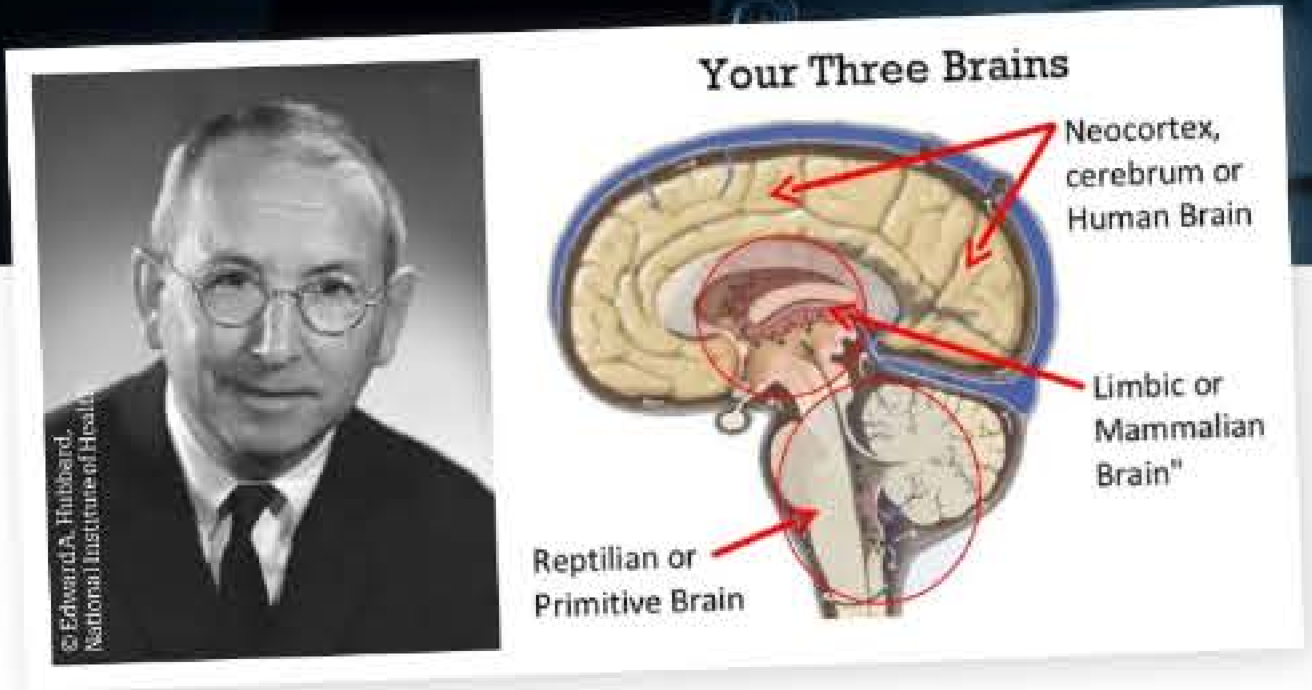
Your Three Brains
Neocortex, cerebrum or Human Brain
Limbic or Mammalian Brain"
Reptilian or Primitive Brain

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Dr Paul Maclean, a leading neuroscientist, developed the famous triune brain theory, which helps us to understand the brain in terms of its evolutionary history

looking for feeding grounds. Wherever you get power, prestige and money, you will find them." The high-risk, high-reward environment of the trading floors and financial markets are well suited to the psychopath's unique skill-set, a fact that famously led Hare to quip, "If I wasn't studying psychopaths in prison, I'd do it at the stock exchange."

Even 'successful psychopaths', who Hare prefers to describe as "subcriminal" because of their unethical means of achieving success, are difficult to live with and are almost always damaging to the people closest to them. An inability to form loving, equal relationships and a lack of concern about the emotions and needs of others mean that psychopaths make poor romantic partners. However, although the PCL-R signals a tendency towards promiscuity and multiple, short-lived marriages, some psychopaths do manage to remain married to a single partner for significant periods of time. This may be for contingent reasons, such as their physiological needs being met by their partner or a veneer of married respectability being necessary in their professional arena. Or it could be because their partner finds themselves unable to leave. Where a psychopath indulges in violent, criminal and socially deviant behaviours, the potential for harm to the people around them is significantly increased.

"Psychopaths don't typically consider themselves to be in need of help"

So, what can be done? Sadly, very little. The jury is out on what causes psychopathy: some studies suggest that it is a biological condition, others that environmental factors and a lack of nurturing in a child's earliest years plays a role. It's likely that these often work in conjunction. Advances in brain imaging technology suggest that anomalies in brain structure and function, with poor connections between the frontal and limbic systems, should be the focus of current clinical enquiry. However, the science is in its infancy and not enough is known about variations in non-psychopathic neuropathology for conclusions to be drawn.

Another key problem is that psychopaths don't typically consider themselves to be in need of help. Their specific personality traits can often put them at an advantage in a dog-eat-dog world that prizes individualism. As Hare has observed, "They see nothing wrong with themselves, experience little personal distress, and find their behaviour rational, rewarding, and satisfying... They perceive themselves as superior beings."

For these reasons, psychotherapeutic treatments have no positive effect, and in the absence of any illness, drug regimes also aren't possible. Worryingly, studies of prison populations have shown that forcing psychopaths to take part in talk therapy or empathy training actually makes their offending worse as they find better ways to manipulate and deceive the people around them. This can impact future victims or equip the psychopath with new methods for manipulating prison guards, parole officers and clinicians into believing that they have been reformed.

Research has demonstrated that the only way to curb the worst excesses of a psychopath's behaviour is to appeal to their self-interest. According to guidance issued by the UK Department of Justice, therapists should focus on helping psychopaths to develop the skills that will allow them to get what they want out of life in a "pro-social rather than anti-social way" and therefore keep out of prison.

For those whose lives have been negatively impacted by psychopaths, the bleak clinical outlook will offer no comfort. In many cases, the best advice is to avoid becoming enmeshed with psychopaths in the first place, but given their ability to charm and manipulate even those in the field, this is neither helpful nor realistic. Hare does suggest some ways to reduce vulnerability, however. Firstly, knowledge is the best defence: understanding how psychopaths operate and understanding one's own weaknesses can make it easier to recognise and resist their predatory advances. For those already affected, Hare advocates seeking professional clinical advice and support groups.

Ultimately, Hare counsels that there is no point in entering into a power struggle with a psychopath as they are hardwired to gain physical and mental control over others. Better to cut your losses, recognise that you are not to blame and move on with your life.

THE FUTURE OF THE HUMAN BRAIN

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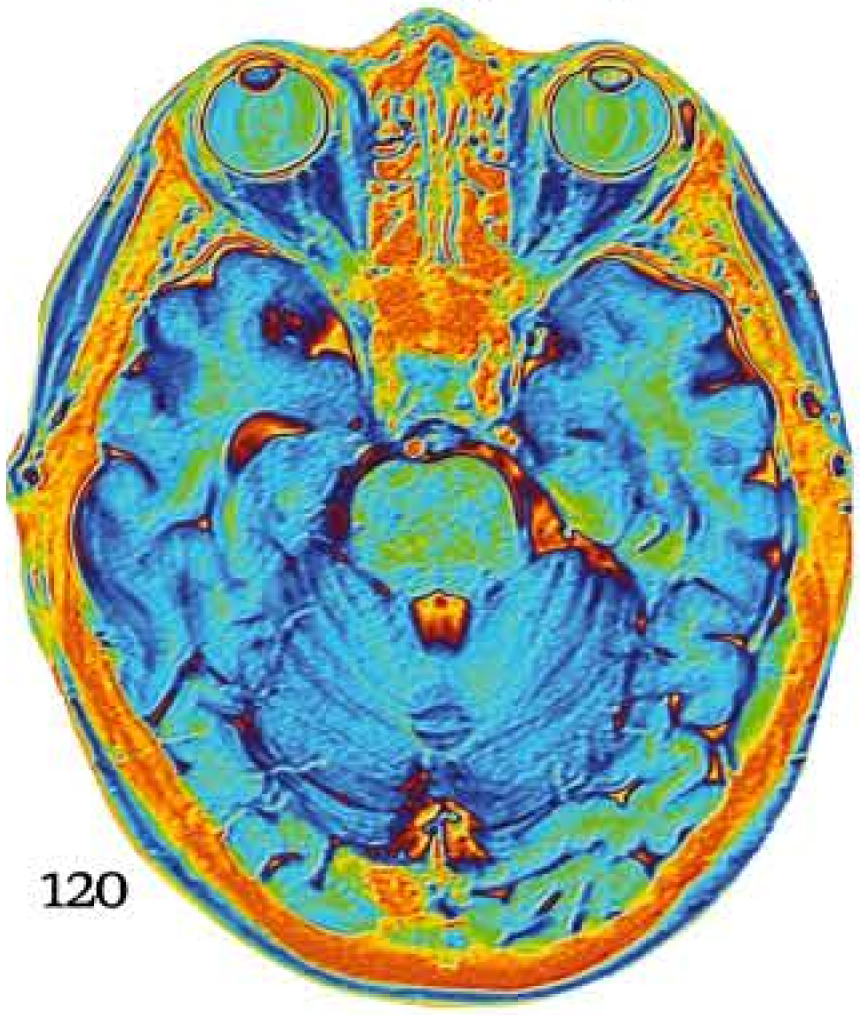

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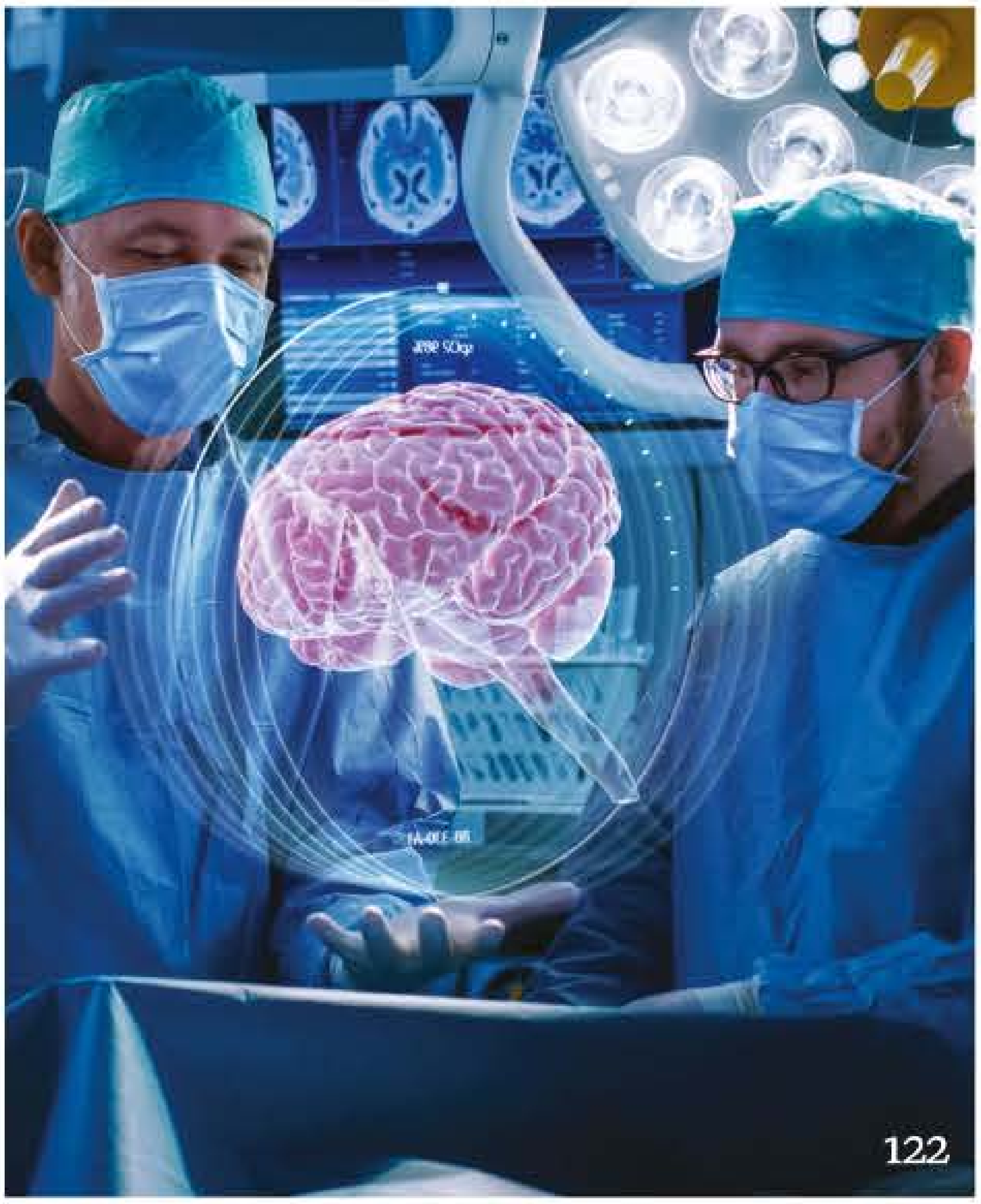

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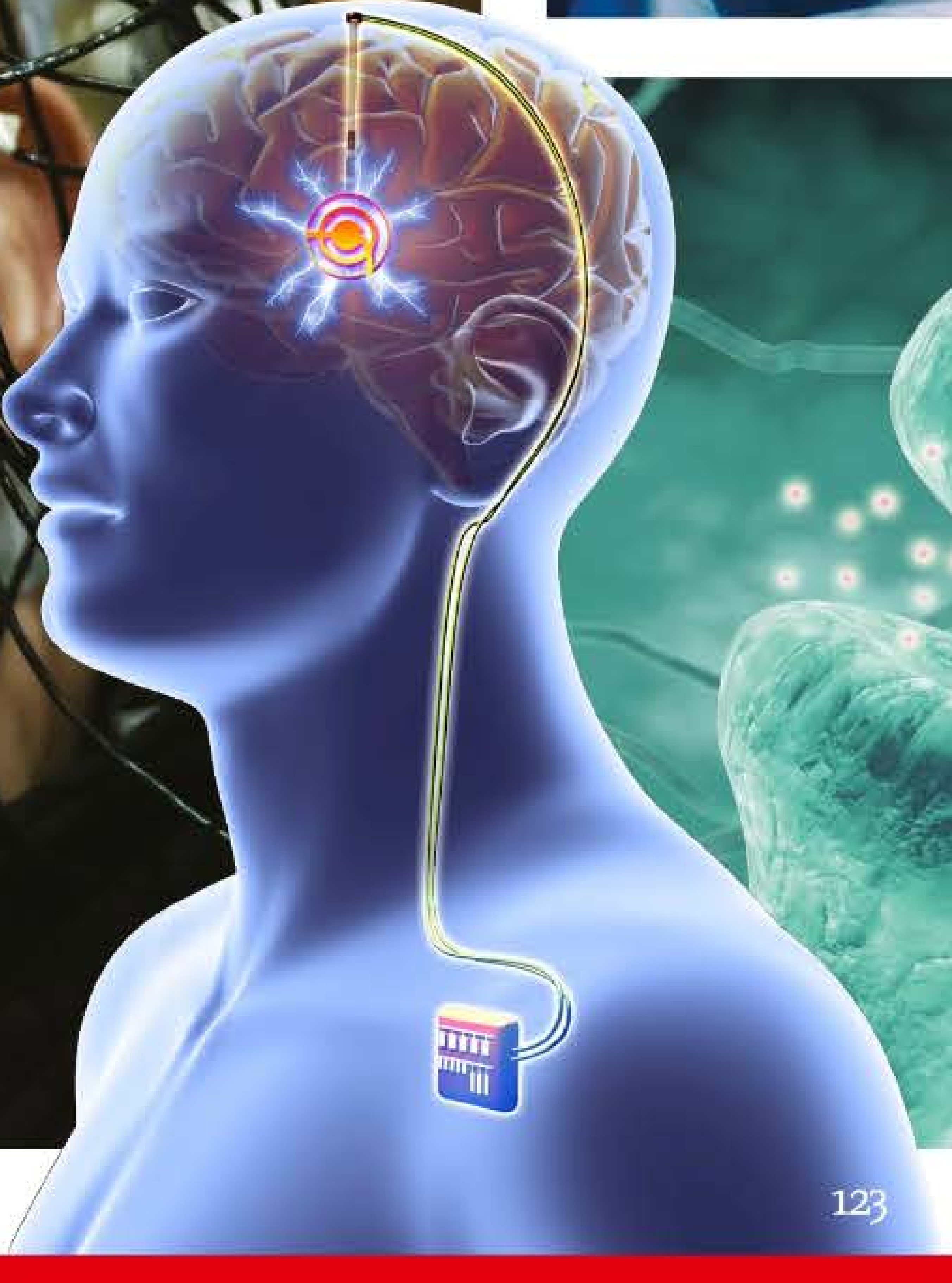

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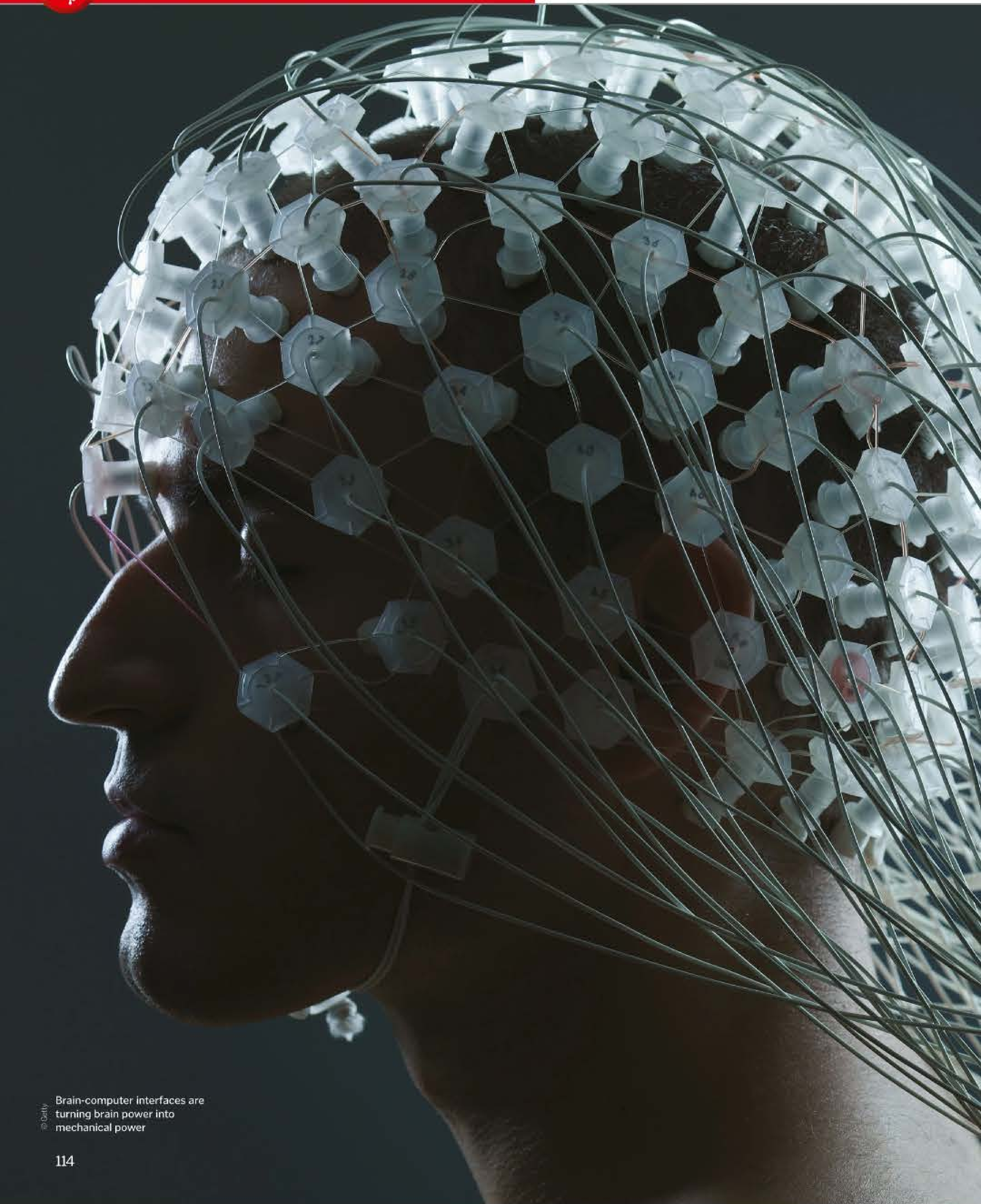

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Brain-computer interfaces are turning brain power into mechanical power

BRAIN TECHNOLOGY

Discover the ways science is hijacking our minds to communicate with machines

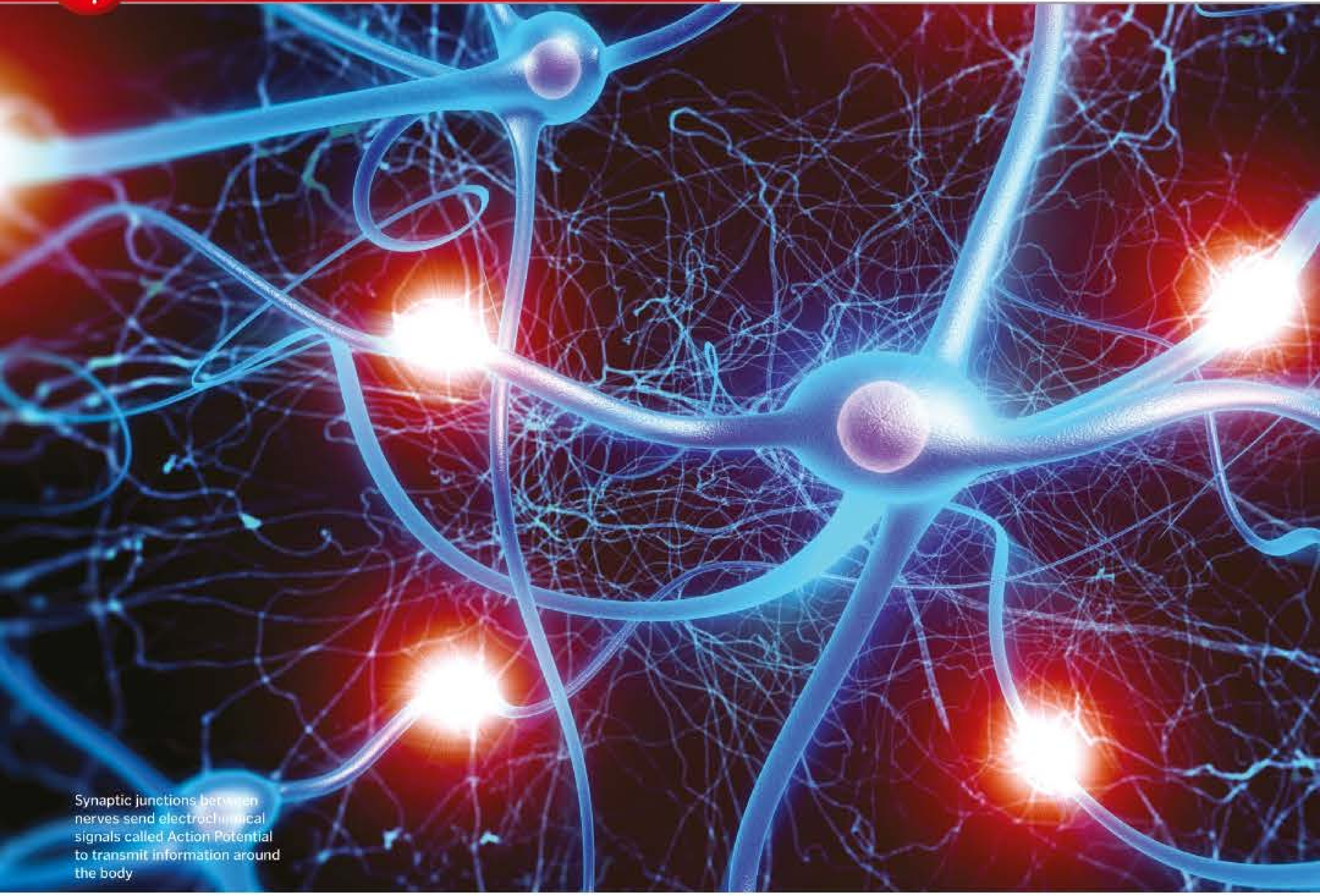
Words by **Scott Dutfield**

As the control centre for our entire bodies, the brain dictates every aspect of the physical being and our mental ability. From the simple act of moving a limb to complex thought and defining our personalities, millions of electrical-conducting neurons act as microscopic messengers, sending instructions around the body. But what if science was able to hijack those messages and start sending a few of its own?

Theoretically, by redirecting some of the electrical signals and sending them through pieces of technology, scientists are able to use brain power to control machines. This technique of hacking the brain has been realised with the creation of the brain-computer interface (BCI). Typically split into three categories, BCIs facilitate the communication between the brain and a machine.

The first method of creating a BCI involves the use of invasive measures. This is where electrodes are surgically implanted within the brain's cortex and then monitor the activity of billions of neurons in the brain – around 86 billion to be precise.

The electrical data collected can then be transmitted through sensors and trigger a response by linked machinery. This method, however, is dangerous and can come with several side-effects.



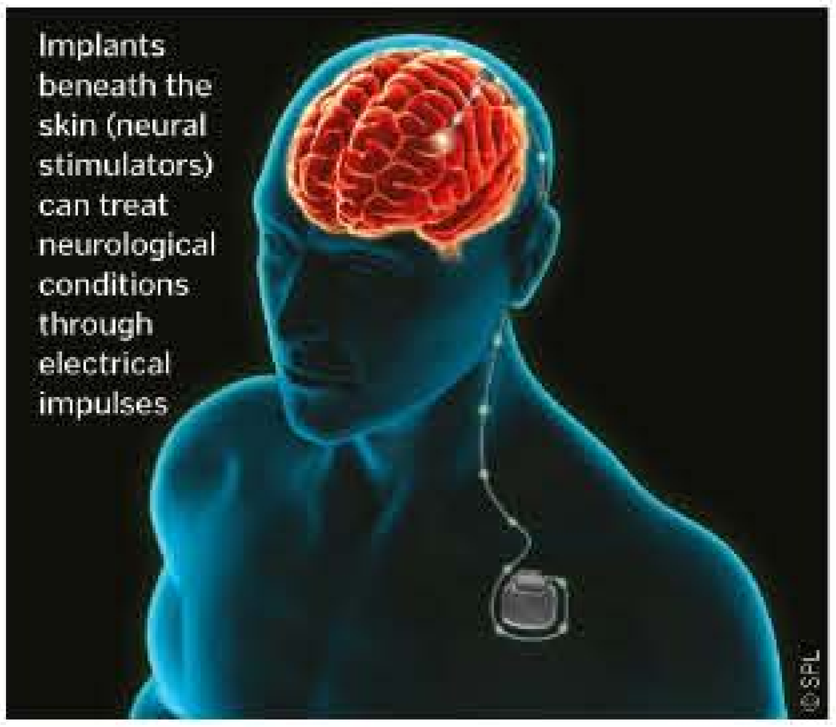
Synaptic junctions between nerves send electrochemical signals called Action Potential to transmit information around the body

Ditching the scalpel for high-tech headgear has made waves as a non-invasive way to mechanically interpret brain signals. Known as electroencephalography (EEG), to map the brain's activity a bald cap is placed on the head, which is speckled with electrodes. Each one monitors the changes in voltage between neurons in the brain. However, using EEG comes with a certain level of difficulty. Unlike the more invasive measures, an EEG has to pick up signals beneath the skull, which can act as an electrical barrier. Almost like looking through frosted glass, EEPs can see there is something on the other side, but the image isn't sharp enough to decipher exactly what the image is. This is how the majority of EEGs are currently operating – they are able to distinguish the location of brain activity and neuron excitation but can struggle to fully interpret it.

> "EEPs can see there is something on the other side, but the image isn't sharp enough to decipher exactly what it is"

Compromising between both invasive and non-invasive approaches, a semi-invasion approach is also being used to combat the paralysing effects of patients with spinal cord injuries. Known as electrocorticography (ECoG), a grid of electrodes is placed beneath the skull on the brain's surface, with an external coupling on the patient's head. This enables scientists to connect directly with the electrode grid and rely on neurological information provided in real-time.

Hijacking the brain in this way to create these brain-to-computer interfaces is not a new concept and has been in development since the 1970s at the University of California. Early attempts to use this emerging technology focused on its medical capabilities, in particular the creation of neuroprosthetics. During the technology's conception – and indeed, still to this day – prosthetics are restricted in their ability to fully replicate lost or paralysed limbs. However, imagine if there was a way to replace or repair the connections between the brain and damaged areas of the body. This is where neuroprosthetics can revolutionise recovery through BCIs. Still in its relative infancy as a branch of medical engineering, today's technology has seen some of the first neuroprosthetics put into practice. Using implanted electrodes, scientists have been able to collect the neurological activity



Implants beneath the skin (neural stimulators) can treat neurological conditions through electrical impulses

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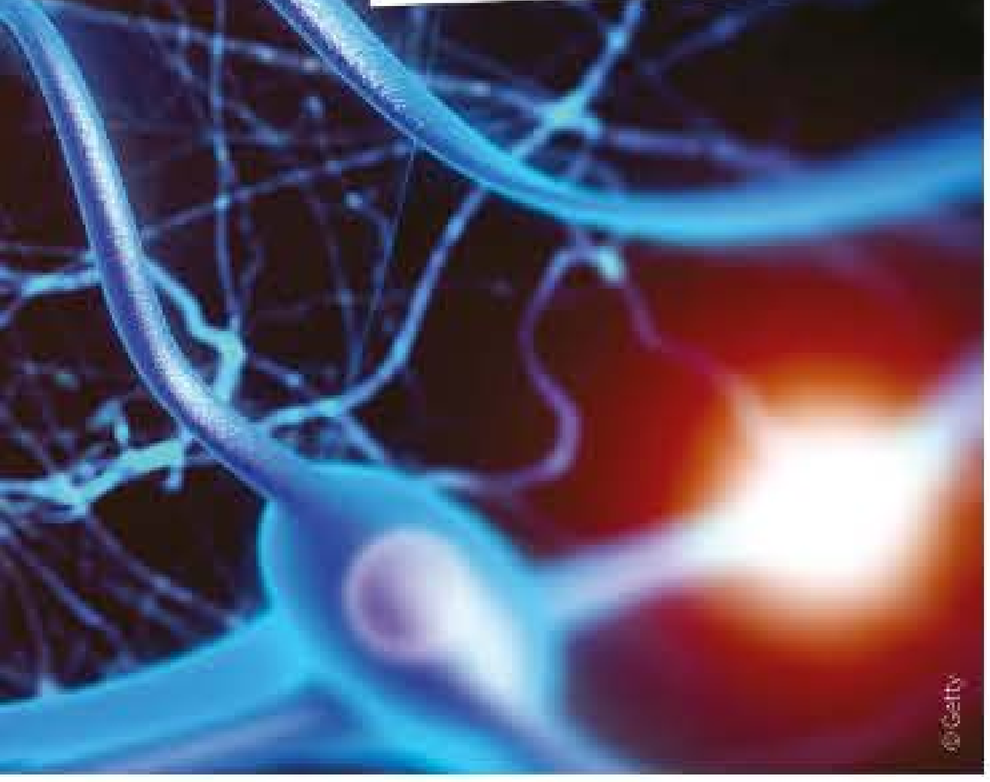
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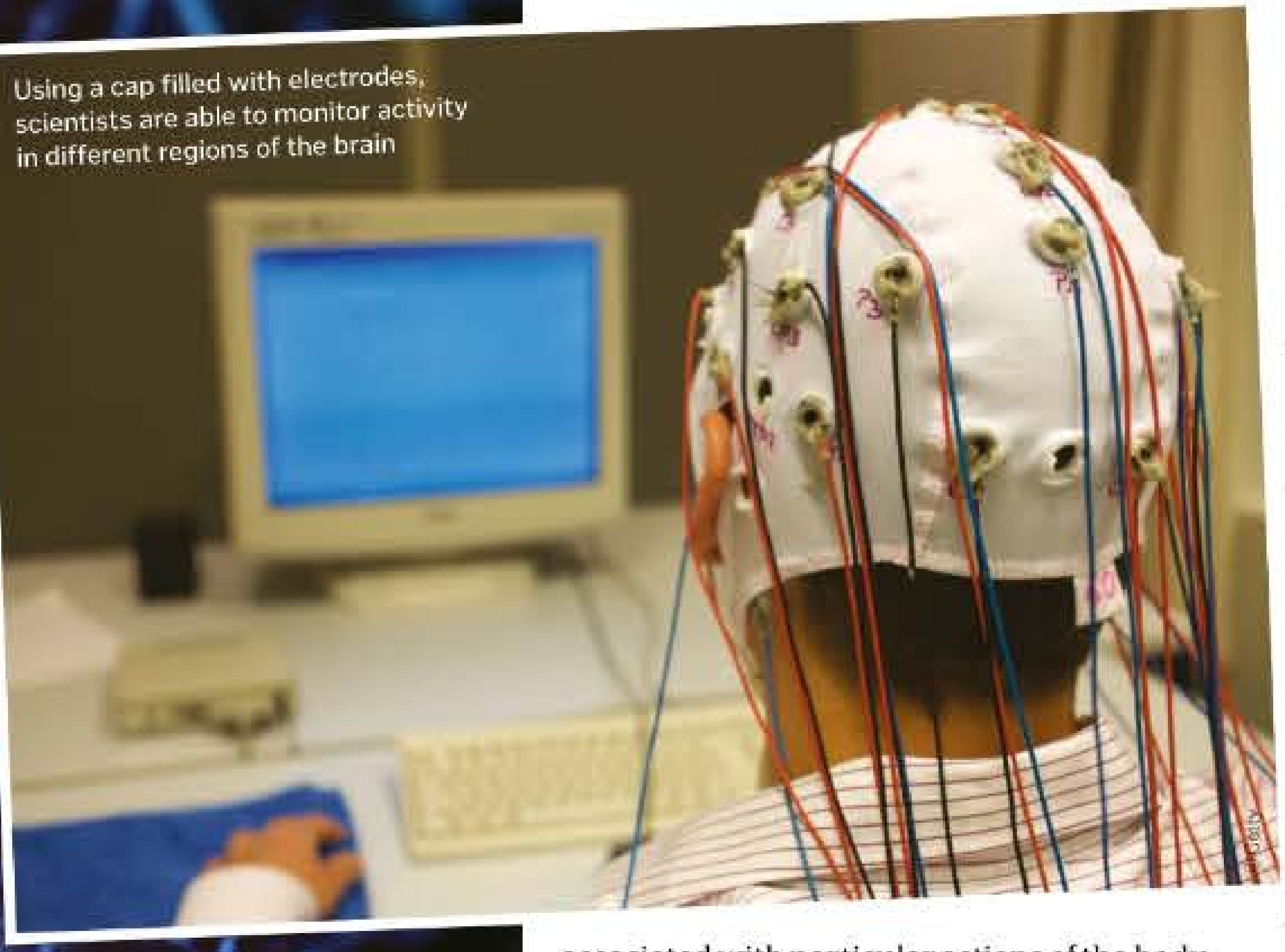
Using a cap filled with electrodes, scientists are able to monitor activity in different regions of the brain

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associated with particular actions of the body, for example raising an arm. This collected information is the electrical firing patterns between nerves, sending signals to and from the brain. Using a BCI, these patterns are then decoded and translated into an electrical signal to command an artificial limb. In cases where patients are missing a limb, the BCI simply completes the communication from the brain to a now-mechanical limb.

A similar approach can be applied to those with paralysed limbs. Developed as a biological bridge between brain and body, neural bypass technology is currently being researched to send brain commands digitally outside the body, through electrical cables to sensors on the skin. In turn, the electrical signals reach their destination, delivering the message to move. While the existing technology is still primitive, it has yielded some great results to date and suggests a promising future for neuroprosthetics and the treatment of paralysed patients.

The creation of prosthetics has not been the only way in which BCIs can further medical advancements. One area of medicine seeing excellent treatment results with the aid of brain technology are those suffering from neurological conditions such as Parkinson's disease and epilepsy. The predominant symptom of epilepsy is the occurrence of seizures. These physical convulsions are the result of naturally unmanaged electrical activity by nerves in the brain. Over the years, scientists have created a device known as a neurostimulator to act as a voice of reason for these unruly neurons and to prevent the development of a seizure.

First using a non-invasive BCI cap, external electrodes are able to locate the site of neuron excitation prior to a seizure, almost like a brain GPS. Once the final destination is identified, invasive measures are taken to place small electrodes at the site. These electrodes are attached by tiny conductive cables to a small stimulator device, which can be placed on top of the skull, beneath the scalp or extended down to the chest. Continually monitoring the activity in that area, the neurostimulator will detect when the neuron activity begins to show signs of a seizure and deliver its own electrical impulse along the cables and through the electrodes to

Sebastian Reul was the first champion of the BCI race at the 2016 Cybathlon

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Neurogaming

Could the future of gaming by controlled by our minds?

At the world's first international Cybathlon, back in 2016, thousands gathered to witness a new form of competitive gaming. Using state-of-the-art technical-assistance systems, research teams competed across several races, including an exoskeleton race, prosthetic arm race and even a BCI race. Equipped with an EEG cap, players competed against one another to race on-screen aviators around a digital track.

As a way to increase awareness for research of assistance systems, research teams at the Cybathlon are now also showcasing the future potential of EEG in games. Virtual and augmented reality come to the forefront of entertainment; the next big step in gaming could come in the form of brain controllers. Much like the work of EMOTIV, other BCI developers like Neurable are taking the principles of EEG and applying them to virtual entertainment.

Paired with a VR headset, Neurable's EEG cap calibrates the brain's firing patterns when attempting to interact with a virtual object. Once attuned to the brain's synaptic behaviour, wearers are quickly able to move objects in a virtually created world and even draw images. This collaboration between BCI's and gaming technology could open up a whole new world of immersive gaming.

the neurons. This, therefore, regulates the activity and prevents the occurrence of a seizure. The neurostimulator works in a similar way as a traditional heart pacemaker, only for the brain.

Commonly known as electroceuticals, researchers have also created wearable devices to treat similar neurological conditions, even attempting to tackle obesity. As biological messengers, each of the billions of neurons firing away in our heads send instructions to the rest of the organs and tissue in our bodies. By artificially stimulating parts of the brain, wearable tech developers, such as Modius, have created sleek EEG headsets to trick the brain into creating instructions at the touch of a button. In the case of the Modius headset, electrodes are placed behind the ears and, when activated, the headset will send subtle electrical impulses past the skin and into the vestibular nerve. Once artificially excited, this nerve in turn is said to stimulate a region of the brain called the hypothalamus. While having multiple roles to play in the human body, the hypothalamus also affects our rate of metabolism. By sending electrical 'fake news', the Modius headset claims to continually stimulate the hypothalamus, increasing metabolism and thus reducing body fat.

> "However, the technology is also paving the way for mind-controlled military equipment, such as drones"

Although BCIs are revolutionising the way we understand how our brains work, devices are also being developed to expand our capabilities across several industries. At some point as children – or indeed as adults – we've always wanted to possess the powers of our favourite superheroes. From the ability to fly or become instantly invisible, BCIs are opening the doors to obtain one such power: the ability to move things with our minds. Using EEG technology, several Silicon Valley start-ups are beginning to shed some light on the possibilities of technological telekinesis.

By activating the vestibular nerve in the neck, the Modius headset reportedly increases your metabolism

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Leading the race in commercial EEG is EMOTIV, a San Francisco-based company that has developed a wearable headset to access your brain power. With only a few sensors, EMOTIV's headset requires the user to first imagine moving a ball, for example. While doing so the electrodes record the patterns of neuronal activity in the brain. With a reference pattern, accompanying software will drive a remote ball when the same pattern is activated again, allowing you to simply think about moving the ball and it will begin to roll away. This simple yet effective concept is now enabling the development of more complex systems of EEG-driven technology.

The United States has taken note of its future potential in combat. The US Defense Advanced Research Projects Agency (DARPA) has invested in several research projects dedicated to developing BCIs for medical use as treatments. However, the technology is also paving the way for mind-controlled military equipment, such as drones. Trialling the technology back in 2017, DARPA reportedly succeeded in flying drones in a simulation using BCI technology – think left and the drone would follow suit. This concept of drones driven by brain power can be seen in many Kickstarter campaigns, but thus far these have enjoyed limited success.

Social media giant Facebook is also trying its hand at using our brains to further expand the ability of social media. Sharing our thoughts and feelings online has quickly become the norm in today's social media-driven society, but what if those thoughts could be typed and sent to our Facebook feed without even lifting a finger? Announced back in 2017 as one of Facebook's future goals, Mark Zuckerberg and his research and development team are developing a BCI technology whereby people will be able to type at 100 words per minute, five-times faster than traditional tapping on a screen. Initially engineered to help paralysed users access the online platform, the goal is to make the technology accessible to everyone.

Quick typing isn't all that Zuckerberg sees as Facebook's future in brain technology – he also wants to compete in the ever-growing world of virtual reality. Immersive entertainment through virtual and augmented reality is quickly becoming the new norm, and in a speech to Harvard students earlier this year, Zuckerberg

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With the help of an implanted BCI, scientists can create an artificial pathway to connect the brain with robotic limbs proffered the idea that their BCI technology could one day provide a way to navigate through social media. One of the major obstacles Facebook – and indeed any commercial venture into BCI – faces are the ethical implications of electronically accessing the human brain. In a world constantly monitored by technology, from smartphone GPS to targeted advertising, BCI technology comes with new concerns about privacy. Although it is commonly agreed among neuroscientists that the technology to spy on people's minds is far out of reach, continued success in BCI technology could one day see a world reminiscent of the *Minority Report*.

The EMOTIV neural headset allows wearers to control the movement of a robotic ball using only their thoughts

Navigating the brain

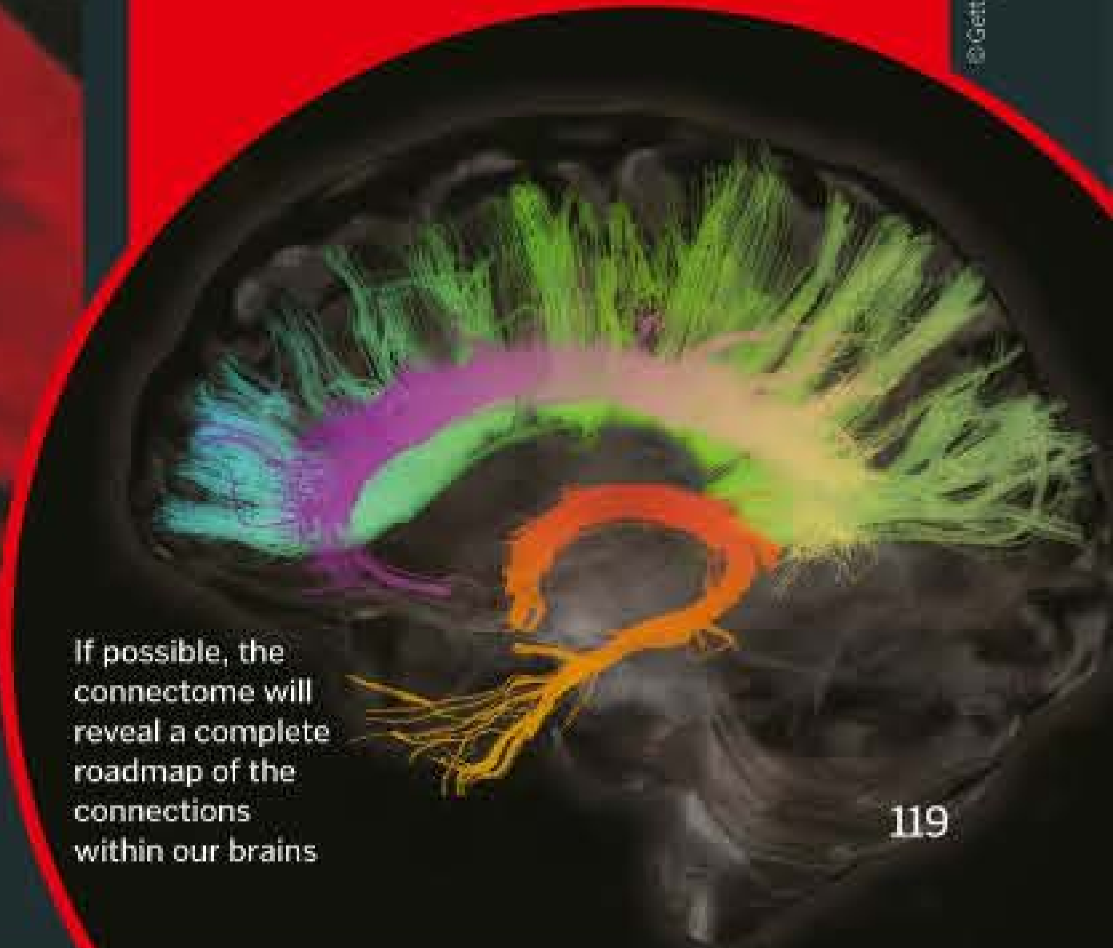
Scientists are working on a way to turn the brain into a neural roadmap

Our knowledge of the brain and its functions is continually growing, allowing scientists to expand technological advancements. Even so, we've only just scratched the surface when it comes to completely mapping the brain.

Brain technology, such as BCIs, offers a window into the regions of the brain that become excited during different bodily functions and even can even relate that activity to different diseases. But the end game for many neurologists and researchers alike is to produce the first complete map of the network of neuron cells and their connections in our brains.

Known as connectomics, neuroscientists around the world are researching ways to map these neural connections to form a final image called the connectome. The theoretical model would act as a Google Maps for the brain, zooming into Street View on a single neural connection. If ever constructed, the connectome would revolutionise the accessibility of brain technologies by presenting exact locations for every aspect of our personality, thoughts and memories.

There is one problem though: there are over 100 trillion of these cellular connections in the human brain. To map one, researchers take extremely thin sections of a brain and scan them via electron microscopes. This process is extremely time-consuming, and in order to fully map a human brain it would take a fleet of electron microscopes and hundreds of researchers decades to produce a final image.


If possible, the connectome will reveal a complete roadmap of the connections within our brains

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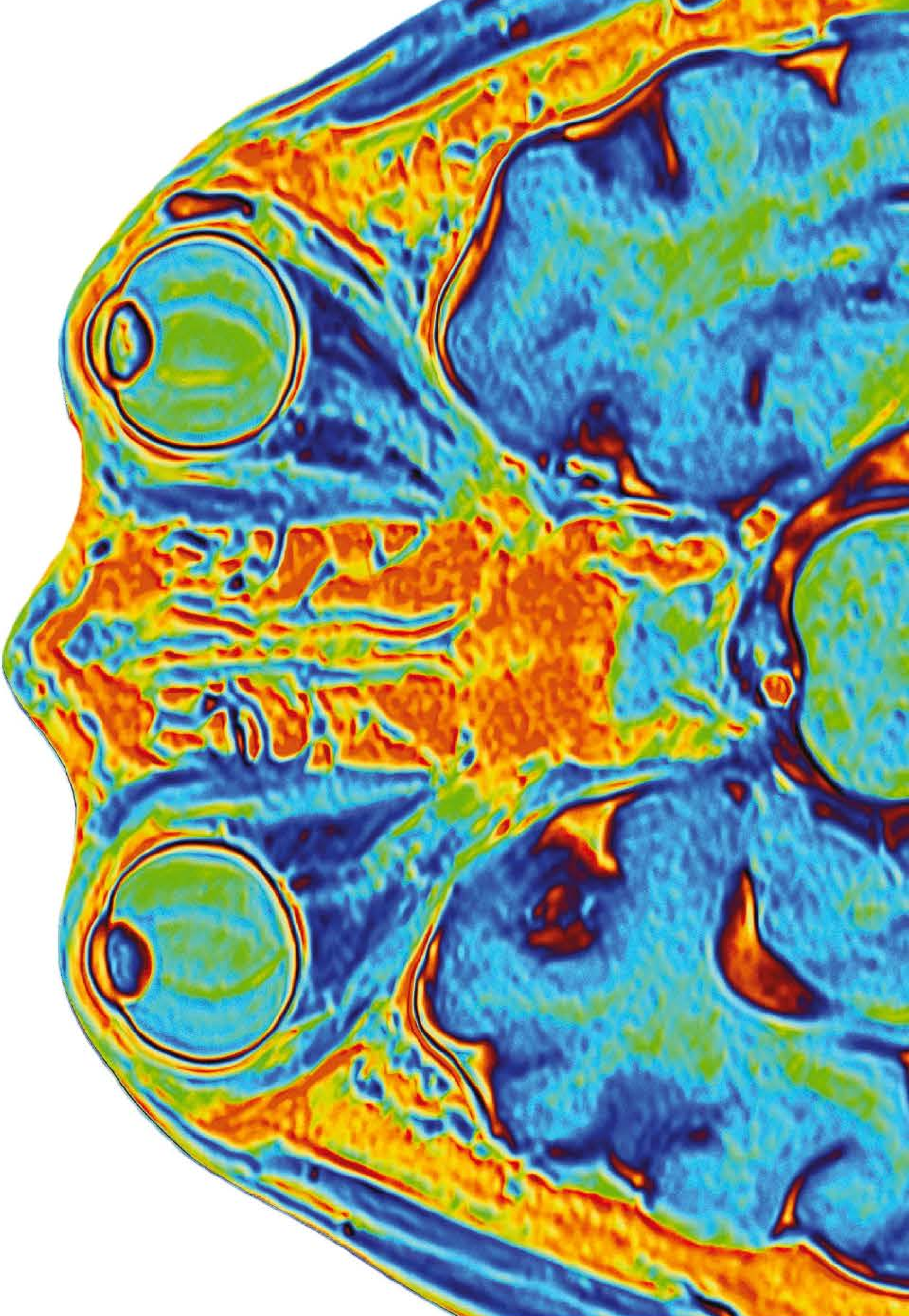
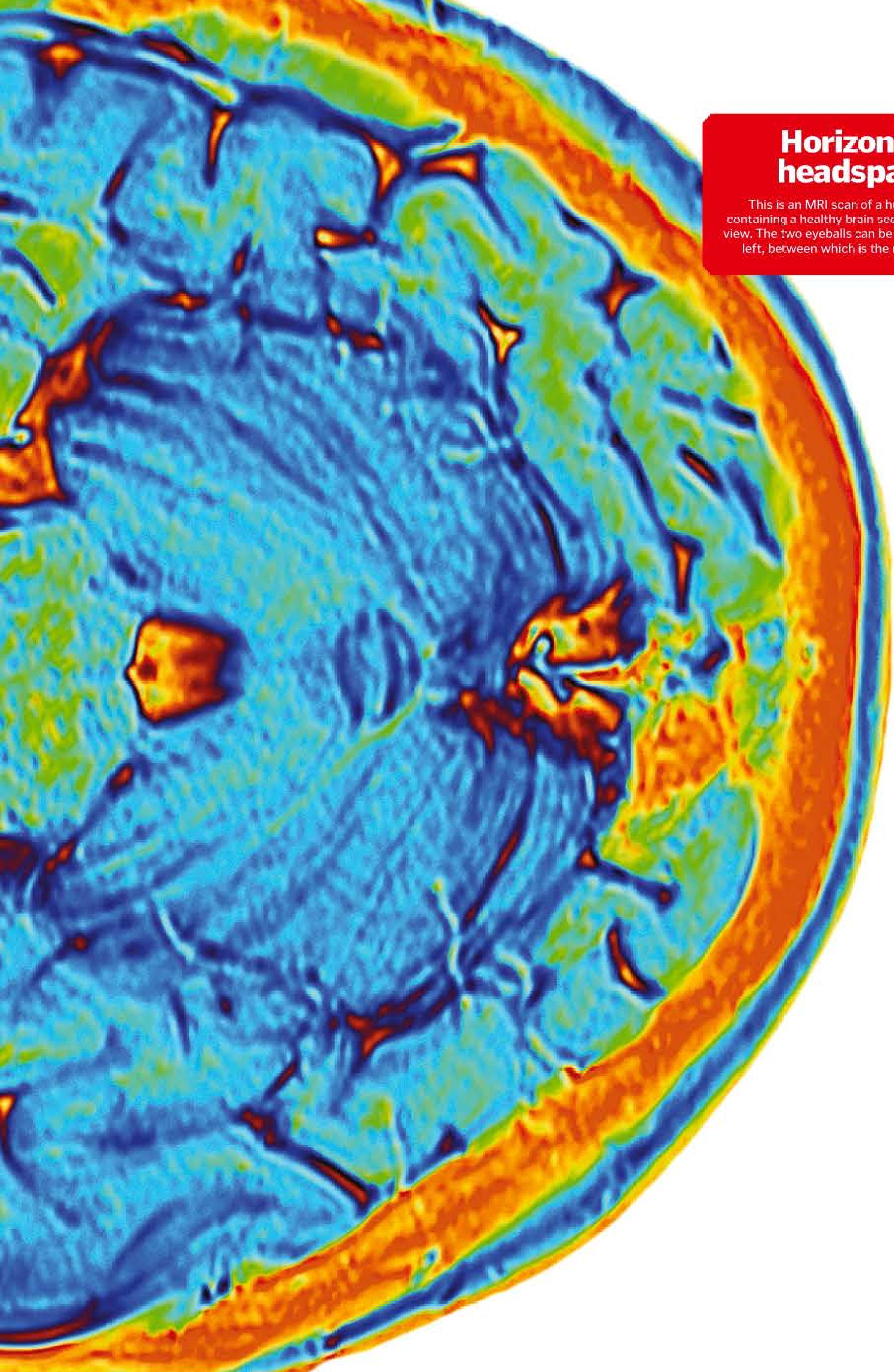




Horizontal headspace

This is an MRI scan of a human head containing a healthy brain seen in horizontal view. The two eyeballs can be seen on the far left, between which is the nasal cavity.

© Getty Images

The ancient Egyptians thought that trephining 'let out' migraines

THE FUTURE OF BRAIN SURGERY

How the surgeon of the future will perform brain surgery

The accolade of the father of modern brain surgery is given to American Harvey Cushing, but its origins can be traced back as far as 6500 BCE. A small hole would be cut into the skull in a procedure known as trephining, and it's thought that brain surgery is the oldest type of surgery. Through the years we have seen the development of anaesthetics, antibiotics, blood transfusions and X-rays; if we continue with the progress that we are making, we could revolutionise brain surgery.

Brain surgery involves using manual hand drills to make holes in the skull. This is a long and complicated process, exposing the patient to a high risk of infection, but technology and software promise to transform this within the next 20 years. A robotic drill could cut down a two-hour procedure to just 2.5 minutes – some 50-times faster. Or perhaps there will be a 'smart needle' that has a camera the size of a human hair, allowing surgeons to see a patient's blood vessels while reducing the risk of injury and bleeding.

Advances in software also hope to make brain surgery much safer and easier. 30 per cent of people with epilepsy don't respond to medication, and the procedure to find which part of the brain to remove is challenging and dangerous. Enter EpiNav, or epilepsy navigation, a pioneering piece of software that creates a three-dimensional map of a patient's brain. This can be used to help surgeons plan complex brain surgery and can guide surgeons in real time.

Given the recent rise in immersive technologies in both the consumer and business markets, perhaps they'll soon be seen in a hospital near you. Augmented reality – where the digital and real worlds combine – would allow surgeons to rehearse surgery, and in theatre they'll be able to see an image from inside the person's brain floating above them. The hope is that these technologies will make surgery safer and less invasive.

The gamma knife

A new piece of technology that means surgery without a scalpel

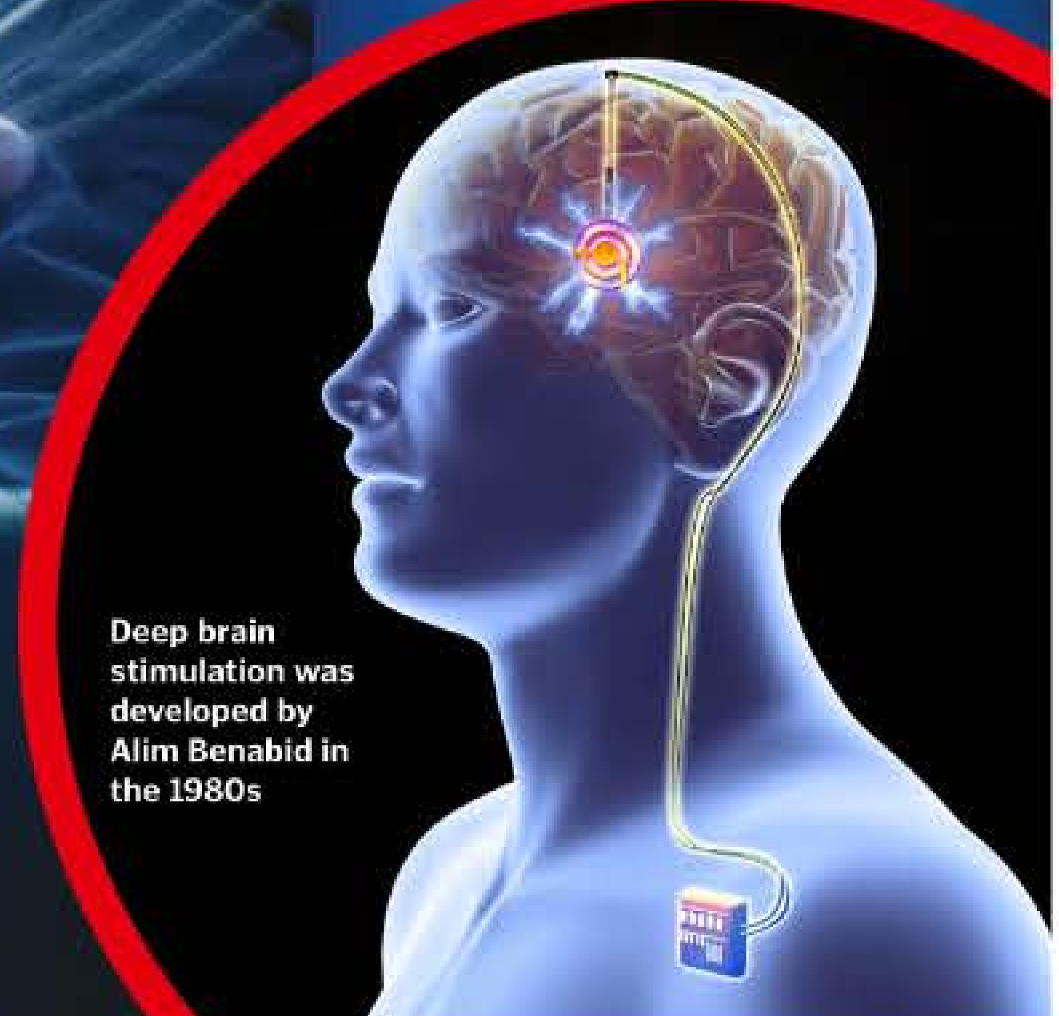
Despite its name, the gamma knife is not a knife – it's a noninvasive type of surgery that uses high-dose radiation therapy in the treatment of brain conditions including tumours, blood vessel lesions and epilepsy. This pioneering technique was invented by Swedish neurosurgeon Professor Lars Leksell and scientist Börje Larsson in the late 1960s as an alternative to traditional brain surgery. More than 1 million patients worldwide have been treated with a gamma knife to date.

The machine uses cobalt-60 as the source of gamma radiation beams. 192 individual beams are focused on the target, with each one having minimal effect on the tissue it passes through. They combine to form one single, high-energy beam, which provides a precise and intense radiation dose. The radiation damages the cancer cells' DNA, slowing their growth or preventing them from reproducing. This results in cell death, and they are then removed by the body.

With this type of surgery less healthy brain tissue is harmed and there are fewer side-effects, less risks and a shorter recovery time. Other types of radiosurgery include linear accelerator systems, which use X-rays to treat lesions, and proton beam therapy, which uses protons or neutrons to irradiate diseased tissues.

The gamma knife can aim at a target that's smaller than the width of a human hair

Future surgeons may use augmented reality to plan surgical procedures



Deep brain stimulation was developed by Alim Benabid in the 1980s

Humans can survive without half of their brain

Types of brain surgery

From removing half of the brain to implanting wires, discover the ways that surgeons perform brain surgery

Neuroendoscopy

This is a small, telescope-like device that allows for the removal of a tumour through the nose, mouth or small hole in the skull and is able to access parts of the brain that otherwise would be too difficult or dangerous via traditional brain surgery methods.

Deep brain stimulation

This surgery involves implanting thin metal wires in the brain. These wires send electric impulses to the brain, which can help to control problems with movement associated with the progressive neurological disorder Parkinson's disease.

Craniotomy

This is the most common type of surgery for brain tumours and involves a surgeon cutting an area of bone from the skull, which exposes the brain. Scans taken before the surgery and a neuronavigation system guide the surgeon to the location of the tumour.

Awake craniotomy

In cases of epilepsy or tumours that are close to a part of the brain that controls an important function such as movement, the surgeon will communicate with the patient to ensure that minimal, if any, functions are harmed. The brain itself does not feel pain.

Hemispherectomy

This rare surgical procedure removes half of the brain and can be used to treat children with severe epilepsy. The remaining side of the brain should be able to do everything that the lost hemisphere was responsible for – an ability known as neuroplasticity.

INTO THE UNKNOWN

Despite how much we know about the brain, there is still much more to uncover

Words by **Baljeet Panesar**

During the Neolithic period, our ancient ancestors practised a primitive form of brain surgery known as trepanning, possibly practising their skills on cows. The ancient Egyptians thought that the heart, not the brain, was the source of human emotions and intelligence, but they came to recognise that injury or damage to one side of the brain could paralyse limbs on the opposite side of the body, as illustrated in the Edwin Smith papyrus, one of the oldest medical texts in the world.

Neuroscience was born roughly 2,500 years ago when Greek physician Hippocrates began to study the brain, an undertaking that led him to deduce that the brain was responsible for emotion, thought, sensations and cognition.

The father of medicine was later followed by the leading physician in the Roman Empire, Aelius Galenus, a man more commonly known as Galen who worked to confirm that the brain does indeed control thoughts and sensations. For 15 centuries after his death, Galen's influence reigned over the medical field, although many of his theories were later disproved. But the Mediterranean did not have a monopoly on uncovering the secrets of the brain.

Da Vinci imagines the theory held in the Middle Ages – the brain has three 'ventricles' c. 1489

In the medieval Islamic world scholars developed the theories of the Greeks and Romans, translating Greek, Persian and Sanskrit text into Arabic, providing the foundation for Western medicine for centuries.

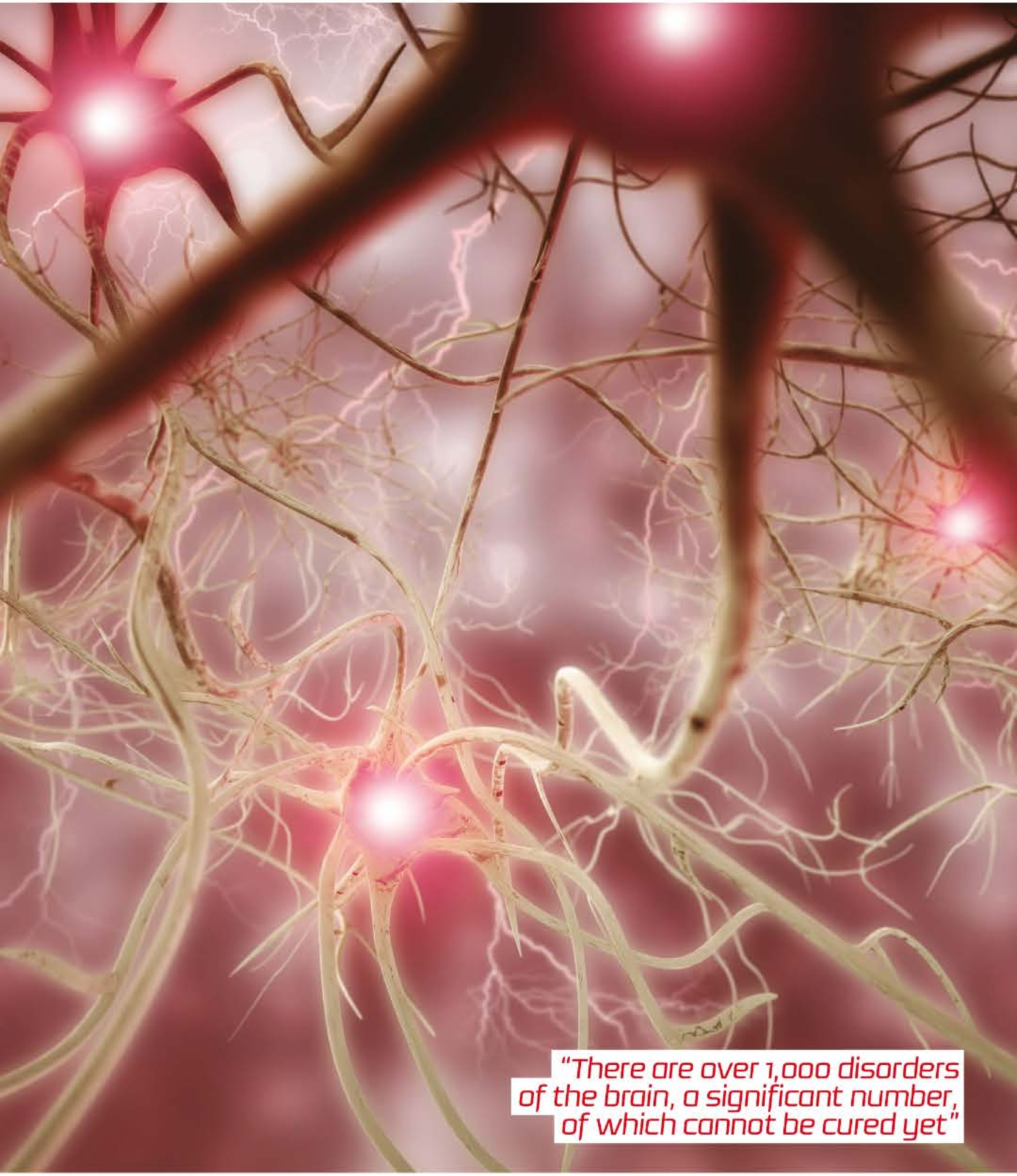
With the groundwork laid in the East, progress continued to be made in Europe. During the 16th century Leonardo da Vinci described experiments on the brain's anatomy, Jacopo Berengario da Carpi wrote the first book on head injuries, and Andreas Vesalius identified some of the brain's and nervous system's structural characteristics, to name just a few milestones that were reached.

While these important steps would make future progress possible, the origins of modern neurosurgery lie with Harvey Cushing, who performed the first brain surgery in 1902 and developed various surgical techniques for operating on the brain. He reduced the mortality rate of surgical brain procedures from roughly 50 per cent to less than ten per cent. Since his death in 1939 developments in technology and diagnostic methods have revolutionised neuroscience as we know it.

However, despite the progress that has been made in recent decades, there is still much to learn and understand. There are over 1,000 disorders of the brain, of which a significant number can't be cured yet and have minimal treatment options. Researchers are trying to determine new ways of treating or even entirely preventing some of these debilitating disorders, and given the growing ageing population worldwide, it's estimated that neurodegenerative disorders will more than double by 2050 – they already affect tens of millions of people.

Neurodegenerative disorders such as Parkinson's disease, Huntington's disease and motor neurone disease are caused by damage to and/or the death of nerve cells (neurones),

Scientists have been able to repair damaged brain cells in mice



"There are over 1,000 disorders of the brain, a significant number, of which cannot be cured yet"

There are several types of chemical messengers that are found in the body

which are the building blocks of the brain that transmit messages from the brain to the body. This results in difficulties with movement, muscle weakness and eventually paralysis. Thankfully, medicine is always advancing.

One promising area of research is stem cell therapy, where damaged or dying nervous tissue could be repaired by transplanting stem cells. These experiments were first performed roughly 30 years ago when foetal brain tissue known as mesencephalic tissue was transplanted into patients with Parkinson's disease. Stem cells have the unique ability of being able to develop into any specialised cell type in the body, from brain cells to skin cells, and in animal experiments and pre-clinical studies induced pluripotent stem cells have been shown to improve motor function – the movements and actions of the muscles.

Each condition has an individual, complicated neurone loss mechanism, and it is this individuality that makes finding effective treatments a long and difficult process. It is hoped that with further understanding of stem cells and disorders, stem cell therapies could be available to help with not just neurodegenerative disorders but also post-stroke therapy and traumatic brain injuries.

In 2018, scientists at UCLA created a new stroke-healing gel that helped mice to regrow neurons and blood vessels that had been damaged by strokes. Unlike other organs in our bodies, such as the liver, the brain has a limited potential for recovery and regeneration, but this study suggested that the brain can recover.

The scientists injected the gel into areas of the brain that had been damaged, and after 16 weeks the brain tissue, including neuronal connections, contained regenerated tissue – a development that marked the first time that this result had ever been seen. It is hoped that this type of approach may one day be used on humans recovering from a stroke.

Recent breakthroughs

Find out some recent discoveries that have been made in the neurosciences

Bowel

Researchers from Johns Hopkins Medicine in Baltimore, US, say they have found evidence to suggest that Parkinson's disease begins in the gut, spreading mutated proteins to the brain via the body's vagus nerve. It's hoped this research will develop methods to detect the disease earlier and improve treatment options.

Brain

A previously unknown region of the brain, the endorestiform nucleus, has been discovered. It's within the interior cerebellar peduncle, an area that helps us with fine-motor control, balance and movement. This research could revolutionise the way neurodegenerative disorders including Parkinson's and MND are treated.

Arm

Researchers from Carnegie Mellon University and Minnesota University (both in the US) have developed the first ever mind-controlled robotic arm that can follow a cursor on a computer screen. This type of non-invasive technology could help improve the lives of people living with paralysis and movement disorders.

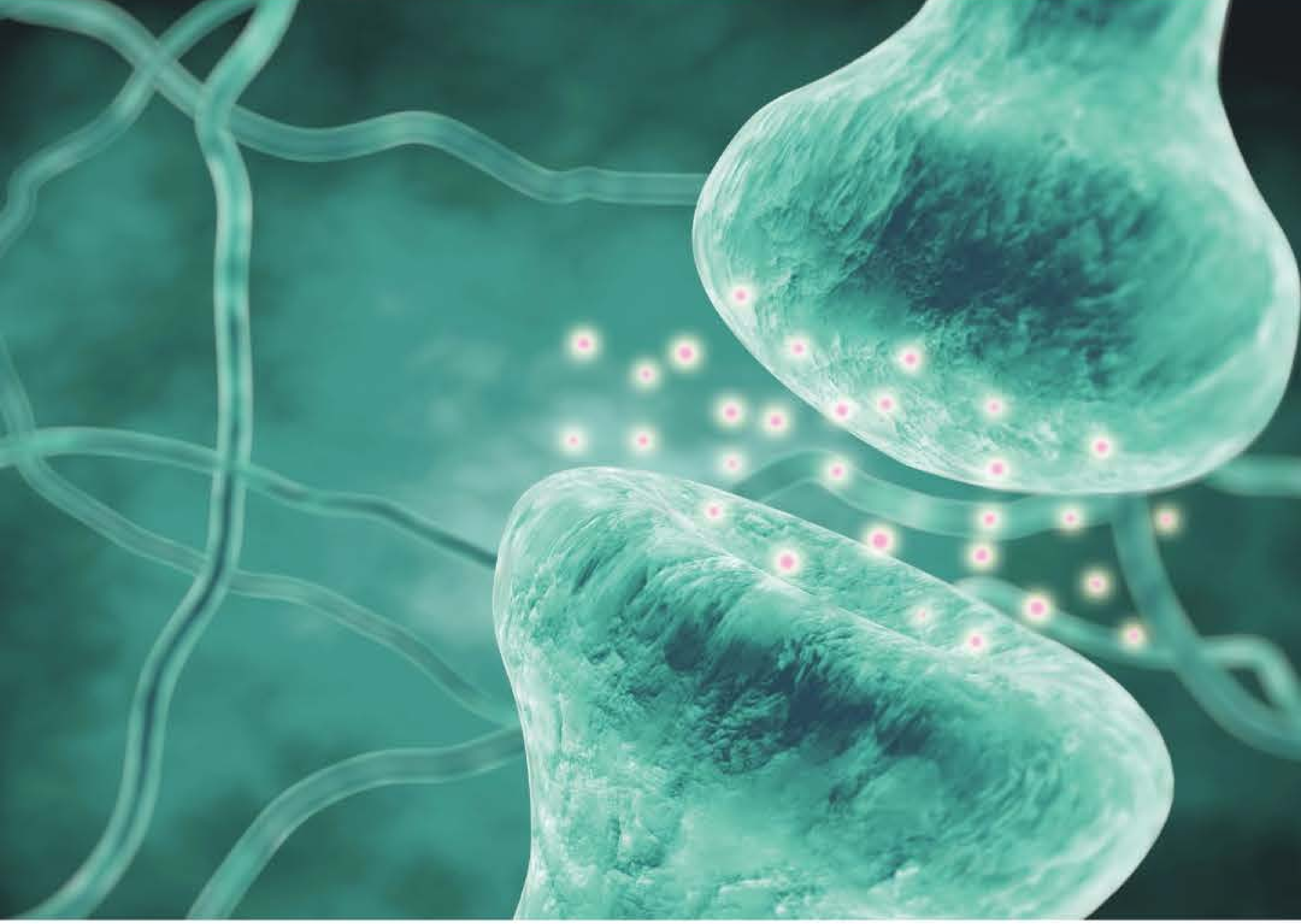
Neurone

Unlike most of our tissues and organs, which can renew themselves during our lives, the growth of new neurones, a process called neurogenesis, is thought to rarely occur in adults. However, new evidence suggests our brains can make new cells into our 90s, a finding that suggests our brains can recover from damage.

In recent years, the idea of using wireless, microscopic 'motes', known as neural dust, has been an area of great interest to researchers. Scientists first made these devices in 2016 at the University of California Berkeley, and in experiments in rats they found that the motes could record and transmit electrical data when they were implanted in a leg's nerve and muscle fibres. Scientists want to reduce the size of motes from roughly one millimetre wide to 50 micrometres wide – half the thickness of a human hair, allowing it to stay in the body for longer than current technology allows.

Although this experiment was not completed on the brain, researchers hope that in the future it could be a form of electroceuticals to treat brain and body disorders, lead to advanced prosthetics and robotics, and communicate with nodes around the body to report on tumours.

We are told that neurones communicate with each other via synapses and that they do so by using chemicals known as neurotransmitters that are able to pass between two neurones – and this is true for many types of neurones in the brain. However, scientists do not yet fully understand how other signalling molecules communicate or behave when influenced by



"Scientists injected a healing gel into parts of the mice's brains that had been damaged by a stroke. After 16 weeks they contained regenerated tissue. It's hoped this approach may one day be used on humans"

neurological medicines. But things could be set to change.

A five-year project known as IARPA MICrONS is attempting to create the largest ever 'roadmap' of neural connections in a cubic millimetre of brain tissue – the largest ever section of brain to be studied in this way to date. Once this project is complete, it will revolutionise our understanding of how the brain processes information and could improve our knowledge of brain diseases and disorders.

The brain's neurones and glial cells (the brain cells that protect neurones) make up the grey matter of the brain together with white matter, brain tissue and axons. But neuroscientists do not know all the different types of neurones and other brain cells or how they work. For researchers to make a complete list of the types of brain cells they will need to identify which cells die, mutate or change in diseases in the brain. Once determined, cell-specific therapies or treatments for epilepsy and degenerative conditions could be developed. But this is no easy feat.

Arguably the most difficult question is what is consciousness? From sweet mint chocolate ice cream and the happiness it brings, to your thoughts and memories, consciousness is the ability to experience the world. In the last couple of decades, researchers have searched for specific neurones that are linked to consciousness. Scientists use the term 'neural correlates of consciousness' to describe the minimum amount of brain activity needed for consciousness, but this doesn't explain what consciousness is, which David Chalmer calls the "hard problem" of consciousness.

The field of neuroscience is more complicated and dynamic than we could imagine; scientists are constantly making new discoveries and developing previous theories. It is this generation of brain science that hopes to uncover the secrets of this 'machine', which could help develop new medication, imaging techniques and treatments for those with brain diseases and disorders, or even possibly prevent them in the first place.

The brain is without doubt evolution's greatest achievement, and thanks to advancements in technology we have learnt more than neuroscientists in previous decades could ever have dared to imagine. If we continue at the same rate of progress, who knows where our desire to study the brain could lead.

If science continues to unearth the brain's many secrets a new dawn of medical progress will become an exciting reality, a world in which the brain's awesome capacity is fully understood and some of the most devastating diseases that can afflict it become a thing of the past.

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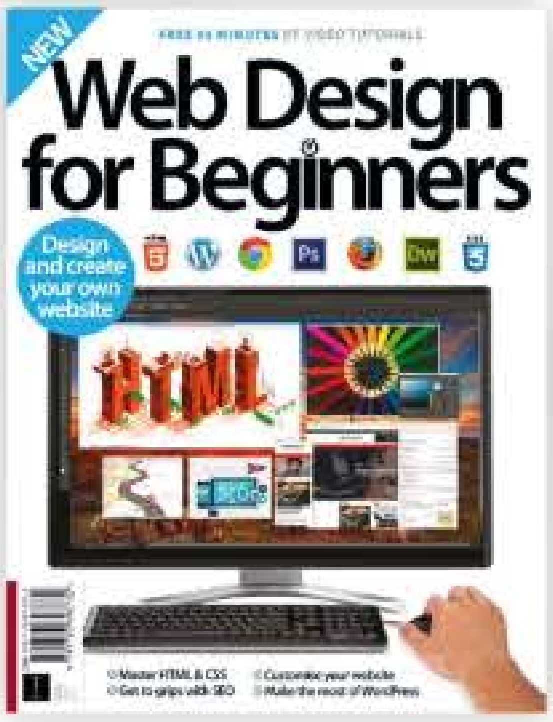

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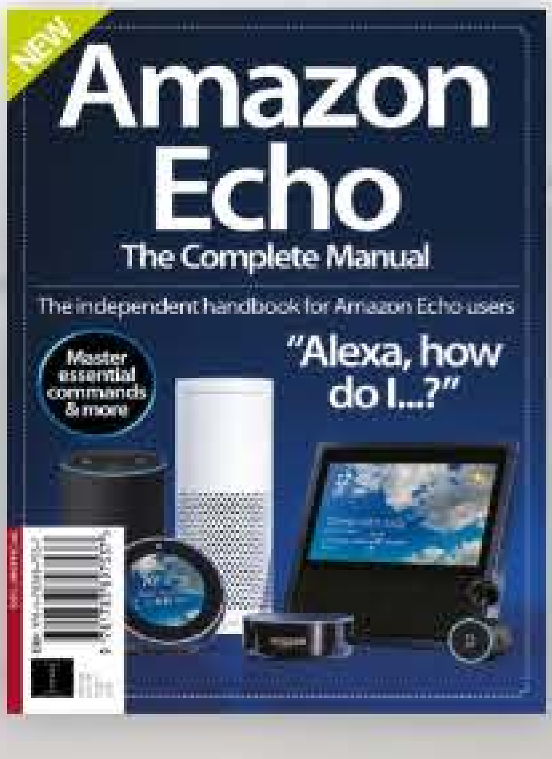

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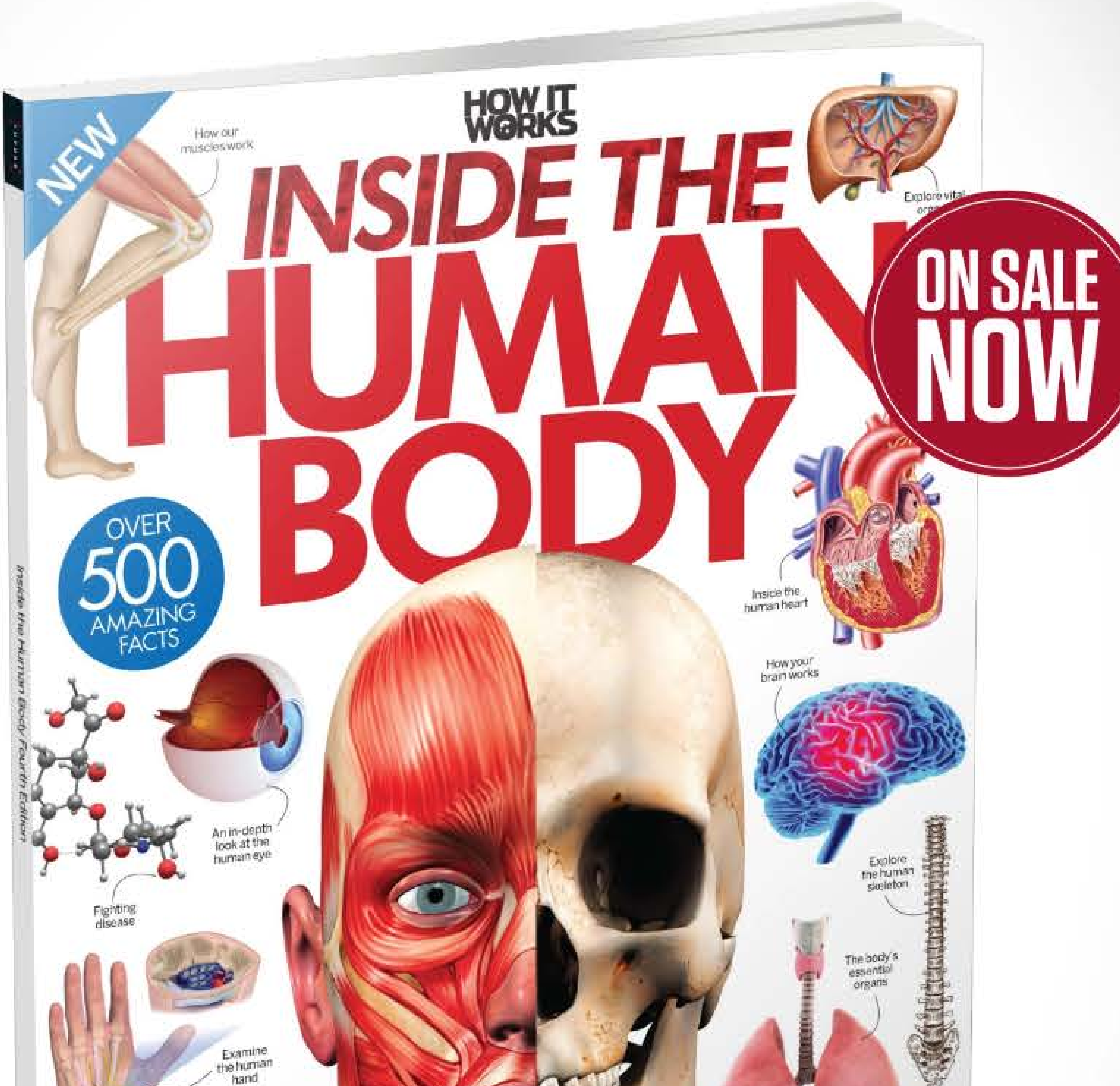

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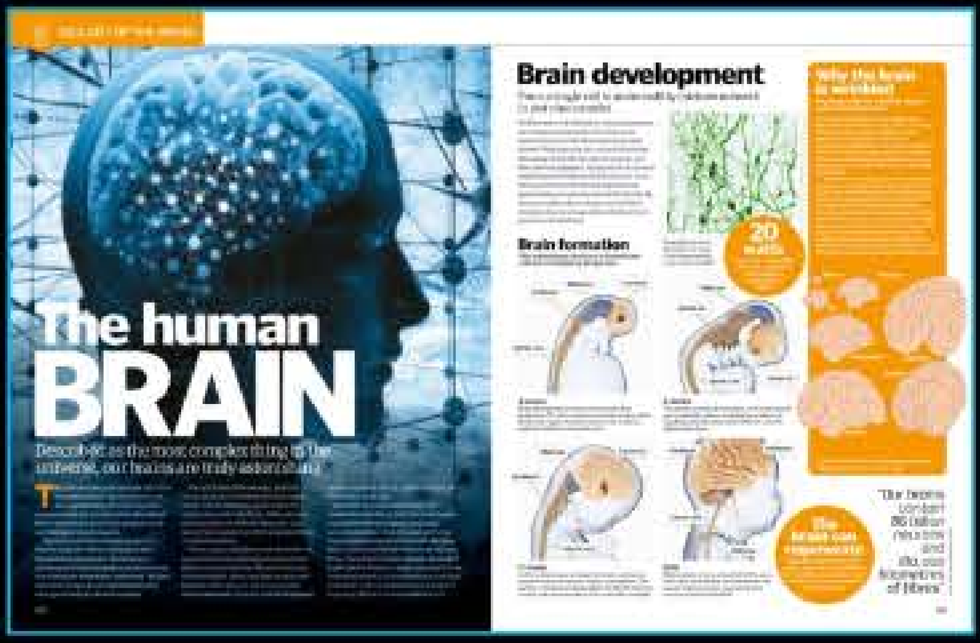

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